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THE DAMPING FACTOR PROVIDED BY FLAT ANNULAR RING BAFFLES FOR FREE FLUID SURFACE OSCILLATIONS

By

Helmut F. Bauer

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ABSTRACT

To prevent excessive propellant motion in the propellant containers of a missile or space vehicle, damping must be introduced into the liquid. This is usually performed by conventional type baffles attached to the tank wall. The most commonly used baffle is a flat annular ring attached to the inner wall of the container. The damping provided by this type of baffle has been given by J. W. Miles in an analytic formula. Since for certain baffle locations part of the baffle is not subjected to the fluid during one slosh cycle, the efficiency of the baffle is reduced. Miles' formula has been corrected to take care of this effect. The new damping factor agrees closely with measured damping factors for annular ring baffles. The results show the variation of the damping factor with the width and location of the baffle, as well as the effect of the amplitude of the fluid oscillations.

The influence of a multi-baffle arrangement and the effect of the distance between baffles are also presented.

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LIST OF SYMBOLS

Symbol	Definition
α	fractional part of cross section occupied by baffle
γs	slosh damping factor
d	depth of baffle below free undisturbed fluid surface
a	tank radius
w	baffle width
ζ_w	liquid surface amplitude at the tank wall
D	distance between baffles
b	distance from tank center to inner baffle rim
$\bar{\alpha}\pi a^2$	effective baffle area of submerged baffle
N	number of baffles submerged in the liquid
M	number of baffles above undisturbed free fluid surface
$\bar{\alpha}^* \pi a^2$	effective baffle area of a baffle above the undisturbed free fluid surface

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SUMMARY

The damping provided by flat annular ring baffles is given in an analytic formula based on the results of J. W. Miles. Corrections have been introduced for the damping factor when part of the baffle is not subjected to the liquid during a slosh cycle. An effective baffle area has been determined, which is a function of the width w of the baffle, its location d below the surface, and the maximum amplitude ζ_w of the liquid at the tank wall. The theoretical formula obtained agrees with experimental results. The influence of more baffles and their distance to each other has also been determined.

INTRODUCTION

Stability and flight control of a missile or space vehicle is considerably affected by the sloshing of the liquid propellants. The tendency in modern space technology is toward a steady increase in size of space vehicles. As their diameters become larger, the natural frequencies of the propellant become lower. This indicates a closer grouping of the sloshing frequencies to the control frequency and thus a larger response of the propellant. Also, with the increasing size of the tanks, the wall friction provides insufficient damping of the propellant to maintain stability. Detrimental effects of propellant sloshing can be prevented by the following methods.

1. Proper tank geometry, i.e., subdivision of tanks by longitudinal walls, which decrease the modal sloshing masses, distribute them to various modes, and also increase the Eigen-values of the propellant.

2. Proper tank location, if possible.

3. Proper control system values.

4. Introduction of mechanical baffles [1, 2, 3, 4].

In the latter case, to which special attention will be devoted here, usually the conventional type baffles, in the form of annular rings attached to the inner walls of the tanks, are used. The effect of this type of baffle upon the damping of the propellant has been roughly predicted by J. W. Miles [5]. A circular cylindrical tank of radius a is filled with fluid to a depth h. An annular ring baffle of area $\alpha\pi a^2$ is attached to the inner wall of the tank at a distance d below the free fluid surface. Miles found that the damping ratio of this annular ring is proportional to the three-halves power of the ring area and to the square root of the liquid amplitude. Furthermore, the location of the baffle has a strong influence and is approximately proportional to the reciprocal e-function. Extensive measurements [6, 7, 8] have been performed by various institutes and have confirmed these results to a certain extent. It was found that practical application of the theory could be extended beyond the range of its original assumption. It was demonstrated that Miles' formula is applicable (within the limits of experimental scatter) up to a baffle area of about one-fourth of the cross sectional area. However, if during one cycle only a part of the baffle is subjected to the liquid, the damping will be different and less than the one obtained from Miles' formula. Only an effective area of the baffle will participate in the damping of the liquid. This will depend strongly upon the location of the baffle with respect to the fluid surface. For a baffle location in the undisturbed free fluid surface plane, only half of the baffle is subjected to the liquid. The damping factor therefore will be expected to be smaller than those given by Miles. This trend will agree with the measured results [6]. Since the baffle ring breaks through the free fluid surface during a slosh cycle, a little higher damping than that given in the following graphs can be expected.

Furthermore, the efficiency of the ring baffle decreases rapidly with its submerged distance, as is indicated by the theoretical and experimental results. This indicates that another baffle should be located at a distance from the upper baffle, so that loss of efficiency of the upper baffle is made up by the other one. Proper spacing of baffles must provide enough damping for the constantly changing liquid height.

REVISED DAMPING COEFFICIENT

A circular cylindrical tank of radius a contains liquid up to a height h above its flat bottom. An annular ring or a series of annular rings with a spacing of D is attached to the inner wall of the cylinder. The upper ring is located a distance d from the undisturbed free fluid surface and has a width w. The ring area is given by $\alpha\pi a^2$, where α is the fractional part of the cross section occupied by the annular ring (Fig. 1). The first mode is the dominant mode of propellant sloshing

in a cylindrical tank with circular cross section. Since the sloshing mass remains practically constant with changing fluid height (it changes only considerably below $h/a = 1$), the damping factor for a single baffle is practically independent of the fluid height. If the baffle is completely submerged during a slosh cycle, the complete part of the cross sectional area

$$\alpha = \frac{w}{a}[2 - \frac{w}{a}]$$

is effective during the whole cycle. For smaller depths of submergence of the ring baffle, part of the baffle area is not subjected to the liquid, depending upon the amplitude of the free fluid surface. This amplitude is measured from the undisturbed free surface location, and its maximum value at the tank wall $r = a$ is denoted by ζ_w. The purpose of this investigation is to include this effect into the Miles' formula. This will result in a reduction of the damping ratio in the region where not all the baffle area is subjected to the liquid.

a. Single Annular Ring Baffle

The damping ratio γ_s obtained for a single annular ring baffle fixed to the inner tank wall of a circular cylindrical tank was obtained [5] as

$$\gamma_s = Ce^{-4.6\ d/a}\ \alpha^{3/2} \sqrt{\zeta_w/a}\ , \qquad (1)$$

where d is the depth of the baffle below the equilibrium position of the free fluid surface, ζ_w is the maximum free fluid surface displacement at the tank wall, and α is the baffle area ratio blocking the cross sectional area. The constant C is obtained from experimental drag measurements of flat plates in an oscillating fluid and has approximately the value 2.83. Figures 2 - 5 exhibit this damping factor γ_s versus various abscissas for various parameters. Figure 2 shows the damping ratio versus baffle submergence d for a constant free fluid surface amplitude with the width of the ring baffle as a parameter. Figure 3 exhibits the damping factor for constant ring baffle width with the surface amplitude as a parameter. The damping efficiency of the baffle reduces considerably with increasing distance of submergence d. For larger surface amplitude the damping ratio increases as $\sqrt{\zeta_w/a}$ (Fig. 4).

For increasing baffle width, the damping ratio increases as (Fig. 5)

$$\left[\frac{w}{a}\left(2 - \frac{w}{a}\right)\right]^{3/2} .$$

At low depth d of the baffle below the free fluid surface, part of the baffle is not subjected to the liquid during one slosh cycle. An effective baffle area ratio $\bar{\alpha}$ should therefore be introduced into Miles' formula instead of α. This effective baffle area will reduce the values of the damping ratio and will therefore give the same trend as the measured damping ratio [6]. The value of $\bar{\alpha}$ depends upon the distance d of the submerged baffle and the free surface amplitude. The baffle area exposed to the liquid at the maximum amplitude of the free fluid surface (cross-hatched area in Figure 6) is

$$A_{\text{segment ring}} = \pi(a^2 - b^2) - \left\{\frac{\pi}{2} a^2 - \left[z\sqrt{a^2 - z^2} + a^2 \text{ arc sin } \left(\frac{z}{a}\right)\right]\right\}$$

$$+ \left\{\frac{\pi}{2} b^2 - \left[z\sqrt{b^2 - z^2} + b^2 \text{ arc sin } \left(\frac{z}{b}\right)\right]\right\} . \qquad (2)$$

The instantaneous baffle area ratio $\alpha_{\text{inst.}}$ is with $b/a = (1 - \frac{w}{a})$

$$\alpha_{\text{inst.}} = \frac{w}{a}\left(2 - \frac{w}{a}\right) - \left\{\frac{1}{2} - \frac{1}{\pi}\left[\frac{z}{a}\sqrt{1 - \left(\frac{z}{a}\right)^2} + \text{arc sin } \left(\frac{z}{a}\right)\right]\right\}$$

$$+ \left\{\frac{1}{2}\left(1 - \frac{w}{a}\right)^2 - \frac{1}{\pi}\left[\frac{z}{a}\left(1 - \frac{w}{a}\right)\sqrt{1 - (z/a)^2/(1 - \frac{w}{a})^2} \qquad (3)\right.\right.$$

$$\left.\left. + \left(1 - \frac{w}{a}\right)^2 \text{ arc sin}\left(\frac{z/a}{1 - \frac{w}{a}}\right)\right]\right\} .$$

This is valid, if $z < b$ $\left(\text{i.e., } \frac{\zeta_W}{a} > \frac{d/a}{(1 - \frac{w}{a})}\right)$, because a complete part of the ring is out of the liquid. In the case that $b \leq z \leq a$, $\left(\text{i.e., } d/a \leq \frac{\zeta_W}{a} \leq \frac{d/a}{(1 - \frac{w}{a})}\right)$, only a partial segment of the ring is not submerged in the fluid; the last three terms (last braces) must drop out of formula (3). In the case that all the baffle area is subjected to

the liquid, i.e., $\frac{\zeta_w}{a} \leq \frac{d}{a}$, the last six terms (last two braces) have to be left out of equation (3) and the instantaneous baffle area ratio is

$$\alpha_{inst.} = \frac{w}{a}\left(2 - \frac{w}{a}\right). \tag{4}$$

The introduction of the value $\frac{z}{a} = \frac{d/a}{\zeta_w/a}$ transforms equation (3) into:

$$\alpha_{inst.} = \frac{w}{a}\left(2 - \frac{w}{a}\right) - \left\{\frac{1}{2} - \frac{1}{\pi}\left[\frac{d/a}{\zeta_w/a}\sqrt{1 - \left(\frac{d/a}{\zeta_w/a}\right)^2} + \text{arc sin}\left(\frac{d/a}{\zeta_w/a}\right)\right]\right\}$$

$$+ \left\{\frac{1}{2}\left(1 - \frac{w}{a}\right)^2 - \frac{1}{\pi}\left[\frac{d/a}{\zeta_w/a}\left(1 - \frac{w}{a}\right)\sqrt{1 - \frac{(d/a)^2}{(\zeta_w/a)^2\left(1 - \frac{w}{a}\right)^2}}\right.\right.$$

$$\left.\left. + \left(1 - \frac{w}{a}\right)^2 \text{arc sin}\left(\frac{d/a}{\zeta_w/a\left(1 - \frac{w}{a}\right)}\right)\right]\right\} \tag{5}$$

or

$$\alpha_{inst.} = A + B + C \tag{6a}$$

where

$$A \equiv \frac{w}{a}\left(2 - \frac{w}{a}\right) \tag{6b}$$

$$B \equiv - \left\{\frac{1}{2} - \frac{1}{\pi}\left[\frac{d/a}{\zeta_w/a}\sqrt{1 - \left(\frac{d/a}{\zeta_w/a}\right)^2} + \text{arc sin}\left(\frac{d/a}{\zeta_w/a}\right)\right]\right\} \tag{6c}$$

$$C \equiv \left\{\frac{1}{2}\left(1 - \frac{w}{a}\right)^2 - \frac{1}{\pi}\left[\frac{d/a}{\zeta_w/a}\left(1 - \frac{w}{a}\right)\sqrt{1 - \frac{(d/a)^2}{(\zeta_w/a)^2\left(1 - \frac{w}{a}\right)^2}} +\right.\right.$$

$$\left.\left. + \left(1 - \frac{w}{a}\right)^2 \text{arc sin}\left(\frac{d/a}{\zeta_w/a\left(1 - \frac{w}{a}\right)}\right)\right]\right\}. \tag{6d}$$

If the maximum amplitude and baffle depth are such that $\frac{\zeta_w}{a} > \frac{d/a}{1 - \frac{w}{a}}$, the effective baffle area is obtained by integrating the various instantaneous values $\alpha_{inst.}$ and dividing them by the integrating interval:

$$\bar{\alpha} = \frac{1}{\zeta_w} \left\{ \int_0^d A \, d\zeta_w + \int_d^{d/(1 - \frac{w}{a})} (A + B) \, d\zeta_w + \int_{d/(1 - \frac{w}{a})}^{\zeta_w} (A + B + C) \, d\zeta_w \right\} . \tag{7}$$

For an amplitude ζ_w of the liquid, satisfying the condition

$$\frac{d}{a} \leq \frac{\zeta_w}{a} \leq \frac{d/a}{1 - \frac{w}{a}} ,$$

the term C in the third integral has to be set equal to zero. In the case that

$$\frac{\zeta_w}{a} \leq \frac{d}{a} ,$$

then the terms B and C are set equal to zero. Rearranging these integrals results in:

$$\bar{\alpha} = \frac{1}{\zeta_w} \left\{ \int_0^{\zeta_w} A \, d\zeta_w + \int_d^{\zeta_w} B \, d\zeta_w + \int_{d/(1 - \frac{w}{a})}^{\zeta_w} C \, d\zeta_w \right\} . \tag{8}$$

The first integral is

$$\int_0^{\zeta_w} A \, d\zeta_w = \zeta_w \frac{w}{a} (2 - \frac{w}{a}) \tag{9a}$$

and represents the case of the baffle completely submerged during a slosh cycle, while the second integral results in

$$\int_d^{\zeta_w} B \, d\zeta_w = - \frac{a}{2} \left(\frac{\zeta_w}{a} - \frac{d}{a} \right) + \frac{2a}{\pi} \frac{d}{a} \ln \left[\frac{\frac{\zeta_w}{a} + \sqrt{(\zeta_w/a)^2 - (d/a)^2}}{d/a} \right] -$$

$$- \frac{a}{\pi}\frac{d}{a}\sqrt{\frac{(\zeta_w/a)^2 - (d/a)^2}{\zeta_w/a}} + \frac{a}{\pi}\frac{\zeta_w}{a} \text{ arc sin}\left(\frac{d/a}{\zeta_w/a}\right) - \frac{a}{2}\frac{d}{a} \tag{9b}$$

and is the value of the partial segment of the ring baffle that is not subjected to the liquid.

The third integral results in

$$\int_{\frac{d}{1 - w/a}}^{\zeta_w} C\, d\zeta_w = \frac{a}{2}\left(1 - \frac{w}{a}\right)^2 \left\{\frac{\zeta_w}{a} - \frac{d/a}{1 - \frac{w}{a}}\right\} -$$

$$- 2\frac{a}{\pi}\frac{d}{a}\left(1 - \frac{w}{a}\right) \ln\left[\frac{\zeta_w/a + \sqrt{(\zeta_w/a)^2 - \frac{(d/a)^2}{(1 - \frac{w}{a})^2}}}{\frac{d/a}{1 - \frac{w}{a}}}\right] +$$

$$+ \frac{a}{\pi}\frac{d}{a}\left(1 - \frac{w}{a}\right)\frac{\sqrt{(\zeta_w/a)^2 - \frac{(d/a)^2}{(1 - \frac{w}{a})^2}}}{\zeta_w/a} - \frac{a}{\pi}\left(1 - \frac{w}{a}\right)^2 \frac{\zeta_w}{a} \text{ arc sin}\left(\frac{d/a}{(1 - \frac{w}{a})\frac{\zeta_w}{a}}\right)$$

$$+ \frac{1}{2}\left(1 - \frac{w}{a}\right)\frac{d}{a}\, a \tag{9c}$$

and represents the contribution of the part of the baffle that is completely out of the liquid during a certain time of a slosh cycle. The effective baffle area is then:

$$\alpha = \underline{\frac{w}{a}\left(2 - \frac{w}{a}\right)} - \underline{\frac{1}{2}\left(1 - \frac{d/a}{\zeta_w/a}\right) + \frac{2}{\pi}\frac{d/a}{\zeta_w/a} \ln\left[\frac{\zeta_w/a + \sqrt{(\zeta_w/a)^2 - (d/a)^2}}{d/a}\right]} -$$

$$\underline{- \frac{1}{\pi}\frac{d/a}{(\zeta_w/a)^2}\sqrt{(\zeta_w/a)^2 - (d/a)^2} + \frac{1}{\pi} \text{ arc sin}\left(\frac{d/a}{\zeta_w/a}\right) - \frac{1}{2}\frac{d/a}{\zeta_w/a}} +$$

$$+ \frac{1}{2}\left(1 - \frac{w}{a}\right)^2 \left\{1 - \frac{d/a}{\left(1 - \frac{w}{a}\right) \zeta_w/a}\right\} - \frac{2}{\pi} \frac{\frac{d}{a}\left(1 - \frac{w}{a}\right)}{\zeta_w/a} \ln \left[\frac{\frac{\zeta_w}{a} + \sqrt{\left(\frac{\zeta_w}{a}\right)^2 - \left(\frac{d/a}{1 - \frac{w}{a}}\right)^2}}{\frac{d/a}{1 - \frac{w}{a}}}\right]$$

$$+ \frac{1}{\pi} \frac{\frac{d}{a}\left(1 - \frac{w}{a}\right)}{(\zeta_w/a)^2} \sqrt{\left(\frac{\zeta_w}{a}\right)^2 - \frac{(d/a)^2}{\left(1 - \frac{w}{a}\right)^2}} - \frac{1}{\pi}\left(1 - \frac{w}{a}\right)^2 \arcsin\left(\frac{d/a}{\left(1 - \frac{w}{a}\right) \zeta_w/a}\right)$$

$$+ \frac{1}{2}\left(1 - \frac{w}{a}\right) \frac{d/a}{\zeta_w/a} \, . \tag{10}$$

If the baffle is completely submerged, i.e., $\frac{d}{a} \geq \frac{\zeta_w}{a}$, then the value of $\bar{\alpha}$ is equal to the underlined term. For the case of the baffle being out of the liquid during the slosh cycle in such a fashion that the inner rim of the annular baffle is not out of the fluid at any time, i.e.,

$$\frac{\zeta_w}{a}\left(1 - \frac{w}{a}\right) \leq \frac{d}{a} \leq \frac{\zeta_w}{a} \, ,$$

the underlined dotted terms are added to obtain the effective baffle area. For

$$\frac{d}{a} < \frac{\zeta_w}{a}\left(1 - \frac{w}{a}\right),$$

i.e., part of the complete annular ring gets out of the liquid during a certain time of slosh cycle, the total formula applies.

The damping ratio γ_s for a single flat annular ring baffle is therefore

$$\gamma_s = Ce^{-4.6 \frac{d}{a}} \bar{\alpha}^{3/2} \sqrt{\zeta_w/a} \tag{11}$$

and is exhibited in Figures 9 through 12. Figures 7 and 8 show the effective area of the baffle versus depth of the baffle for a constant surface amplitude ζ_w for various baffle widths w. It can be seen that the efficiency of the baffle area decreases from the point where part of the baffle is not subjected to the liquid during a slosh cycle; this agrees with experiments [6]. The most efficient location of the baffle

depends slightly upon the surface amplitude as can be seen in Figures 9 through 12. For a surface amplitude of 0.01a, the maximum damping of a baffle is achieved for a location of 0.01a below the undisturbed surface. For an amplitude of the liquid of $\zeta_w = 0.05a$, the maximum damping appears at a baffle location of $d \equiv 0.045a$ below the free fluid surface, while, for $\zeta_w = 0.1a$ for a value of $d \equiv 0.065a$, the maximum damping is achieved. For a surface amplitude of $\zeta_w = 0.2a$, the baffle should be located at a depth of $d = 0.08a$ (slightly deeper) below the undisturbed surface to obtain maximum damping. Figure 10 expresses the damping factors versus depths for various baffle widths with the surface amplitude as a parameter. In Figure 11 the damping factor γ_s is shown versus the surface amplitude ζ_w/a for various locations of the baffle d below the free liquid surface. If the baffle is slightly below the surface, the damping becomes larger for increasing surface amplitude than for its location in the free fluid surface. Then with increasing depth of the baffle, the damping is decreased, but the damping increases with increasing surface amplitude. The influence of the width w of the baffle is shown in Figure 12. Again the damping value γ_s increases with increasing width w, but increases more rapidly for a location of the baffle slightly below the free fluid surface, and exhibits less damping for increasing values d of the baffle depth.

b. Damping Factor of a Series of Annular Ring Baffles

For a series of annular ring baffles, the damping factor can be obtained by superimposing the contribution of each baffle. The nth baffle at a location d + (n - 1) D below the free fluid surface exhibits an effective baffle area of

$$\tilde{\alpha}_n = \frac{w}{a}\left(2 - \frac{w}{a}\right) - \frac{1}{2}\left(1 - \frac{\frac{d}{a} + (n-1)\frac{D}{a}}{\zeta_w/a}\right) + \frac{2}{\pi}\,\frac{\frac{d}{a} + (n-1)\frac{D}{a}}{\zeta_w/a}\,\cdot$$

$$\ln\left\{\frac{\frac{\zeta_w}{a} + \sqrt{\left(\frac{\zeta_w}{a}\right)^2 - \left(\frac{d}{a} + (n-1)\frac{D}{a}\right)^2}}{\frac{d}{a} + (n-1)\frac{D}{a}}\right\} - \frac{1}{\pi}\,\frac{\frac{d}{a} + (n-1)\frac{D}{a}}{\zeta_w/a}\sqrt{\left(\frac{\zeta_w}{a}\right)^2 - \left[\frac{d}{a} + (n-1)\frac{D}{a}\right]^2}$$

$$+ \frac{1}{\pi}\arcsin\left(\frac{\frac{d}{a} + (n-1)\frac{D}{a}}{\zeta_w/a}\right) - \frac{1}{2}\,\frac{\frac{d}{a} + (n-1)\frac{D}{a}}{\zeta_w/a} +$$

$$+ \frac{1}{2} (1 - \frac{w}{a})^2 \left\{ 1 - \frac{\frac{d}{a} + (n - 1) \frac{D}{a}}{(1 - \frac{w}{a}) \zeta_w/a} \right\} - \frac{2}{\pi} \frac{\left[\frac{d}{a} + (n - 1) \frac{D}{a}\right] (1 - \frac{w}{a})}{\zeta_w/a}$$

$$\ln \left[\frac{\frac{\zeta_w}{a} + \sqrt{\left(\frac{\zeta_w}{a}\right)^2 - \left[\frac{\frac{d}{a} + (n - 1) \frac{D}{a}}{1 - \frac{w}{a}}\right]^2}}{\frac{\frac{d}{a} + (n - 1) \frac{D}{a}}{1 - \frac{w}{a}}} \right] +$$

$$+ \frac{1}{\pi} \frac{\left[\frac{d}{a} + (n - 1) \frac{D}{a}\right](1 - \frac{w}{a})}{(\zeta_w/a)^2} \sqrt{\left(\frac{\zeta_w}{a}\right)^2 - \frac{\left[\frac{d}{a} + (n - 1) \frac{D}{a}\right]^2}{(1 - \frac{w}{a})^2}} -$$

$$- \frac{1}{\pi} (1 - \frac{w}{a})^2 \arcsin \left\{ \frac{\frac{d}{a} + (n - 1) \frac{D}{a}}{(1 - \frac{w}{a}) \zeta_w/a} \right\} + \frac{1}{2} (1 - \frac{w}{a}) \frac{\left[\frac{d}{a} + (n - 1) \frac{D}{a}\right]}{\zeta_w/a} . \tag{12}$$

If

$$\frac{d}{a} + (n - 1) \frac{D}{a} \geq \frac{\zeta_w}{a} ,$$

then the effective baffle area is

$$\bar{\alpha}_n = \frac{w}{a} (2 - \frac{w}{a})$$

because the complete baffle is submerged. If

$$\frac{\zeta_w}{a} (1 - \frac{w}{a}) \leq \frac{d}{a} + (n - 1) \frac{D}{a} \leq \frac{\zeta_w}{a},$$

then the underlined part of the formula is added, while for the case

$$\frac{d}{a} + (n - 1)\frac{D}{a} < \frac{\zeta_w}{a}\left(1 - \frac{w}{a}\right)$$

the complete formula applies.

For a baffle located above the undisturbed liquid surface, the same formula can be applied approximately with a slight modification. If the baffle is completely out of the liquid, i.e.,

$$\frac{\zeta_w}{a} \leq \frac{d^*}{a} ,$$

where $d^* = (D - d)$ is the distance of the baffle above the undisturbed liquid surface, the baffle area subjected to the fluid is $\bar{\alpha}^* = 0$. The value D is the distance between baffles. For

$$\frac{d^*}{a} < \frac{\zeta_w}{a} \leq \frac{d^*/a}{1 - \frac{w}{a}} \quad \text{and} \quad \frac{\zeta_w}{a} \geq \frac{d^*/a}{1 - \frac{w}{a}} ,$$

i.e., only a part of the baffle is subjected to the liquid during a slosh cycle, then the effective baffle area contributing to the damping is $\bar{\alpha}^* = \alpha - \bar{\alpha}$. For the mth baffle, this is

$$\bar{\alpha}^*_m = \underline{\frac{1}{2}\left(1 - \frac{m\frac{D}{a} - \frac{d}{a}}{\zeta_w/a}\right) - \frac{2}{\pi}\left(\frac{m\frac{D}{a} - \frac{d}{a}}{\zeta_w/a}\right) \ln\left[\frac{\frac{\zeta_w}{a} + \sqrt{\left(\frac{\zeta_w}{a}\right)^2 - \left[m\frac{D}{a} - \frac{d}{a}\right]^2}}{m\frac{D}{a} - \frac{d}{a}}\right]} +$$

$$\underline{+ \frac{1}{\pi}\frac{\left[m\frac{D}{a} - \frac{d}{a}\right]}{(\zeta_w/a)^2}\sqrt{\left(\frac{\zeta_w}{a}\right)^2 - \left(m\frac{D}{a} - \frac{d}{a}\right)^2} - \frac{1}{\pi}\arcsin\left[\frac{m\frac{D}{a} - \frac{d}{a}}{\zeta_w/a}\right]} +$$

$$\underline{+ \frac{1}{2}\frac{\left(m\frac{D}{a} - \frac{d}{a}\right)}{\zeta_w/a}} - \frac{1}{2}\left(1 - \frac{w}{a}\right)^2\left\{1 - \frac{\left(m\frac{D}{a} - \frac{d}{a}\right)}{\left(1 - \frac{w}{a}\right)\zeta_w/a}\right\} +$$

$$+ \frac{2}{\pi} \frac{\left(m \frac{D}{a} - \frac{d}{a}\right)\left(1 - \frac{w}{a}\right)}{\zeta_w/a} \ln \frac{\frac{\zeta_w}{a} + \sqrt{\left(\frac{\zeta_w}{a}\right)^2 - \left(\frac{m \frac{D}{a} - \frac{d}{a}}{(1 - \frac{w}{a})}\right)^2}}{\frac{\left(m \frac{D}{a} - \frac{d}{a}\right)}{(1 - \frac{w}{a})}} -$$

$$- \frac{1}{\pi} \frac{\left[m \frac{D}{a} - \frac{d}{a}\right]\left(1 - \frac{w}{a}\right)}{(\zeta_w/a)^2} \sqrt{(\zeta_w/a)^2 - \left[\frac{m \frac{D}{a} - \frac{d}{a}}{(1 - \frac{w}{a})}\right]^2} +$$

$$+ \frac{1}{\pi} (1 - \frac{w}{a})^2 \arcsin \left\{ \frac{\left(m \frac{D}{a} - \frac{d}{a}\right)}{(1 - \frac{w}{a}) \; \zeta_w/a} \right\} - \frac{1}{2} (1 - \frac{w}{a}) \frac{\left[m \frac{D}{a} - \frac{d}{a}\right]}{\zeta_w/a} \; . \tag{13}$$

If the value

$$m \frac{D}{a} - \frac{d}{a} \geq \frac{\zeta_w}{a} ,$$

then $\bar{\alpha}^*_m = 0$, while for the case where a partial part of the baffle is only subjected to the liquid during one slosh cycle, the effective area contributing to damping is presented by the underlined part of the formula. This means that this part is used for

$$\frac{\zeta_w}{a} (1 - \frac{w}{a}) \leq \frac{D}{a} - \frac{d}{a} \leq \frac{\zeta_w}{a}.$$

For

$$m \frac{D}{a} - \frac{d}{a} \leq \frac{\zeta_w}{a} (1 - \frac{w}{a}),$$

the total formula is applied for the effective area. Thus the total damping of N baffles of width w submerged in the undisturbed liquid and M baffles of the same width outside of the undisturbed fluid, all of which are apart from each other by the value D, is given by

$$\gamma_s = C\sqrt{\frac{\zeta_w}{a}}\left\{\sum_{n=1}^{N} e^{-4.6\left[\frac{d}{a} + (n-1)\frac{D}{a}\right]} \cdot \bar{\alpha}_n^{3/2} + \sum_{m=1}^{M} e^{-4.6\left(m\frac{D}{a} - \frac{d}{a}\right)} \bar{\alpha}_m^{*\,3/2}\right\}. \tag{14}$$

The result of this investigation can be seen in Figure 13, where the damping factor γ_s is graphed versus its depth d for various baffle width w and fluid surface amplitudes. The distance of the baffles is a constant D = 0.2a. A baffle is located at d = 0 and at d = D = 0.2a. The liquid surface changes from one baffle to the next. Reading the result from the baffle at the location d = D = 0.2a to the left to d = 0 exhibits the damping factor γ_s of the liquid changing its free surface location from one baffle to the next. At d = D = 0.2a, the liquid surface is at the baffle location. With decreasing liquid height, the upper baffle leaves the liquid, while the next lower baffle shifts closer to the free fluid surface. The loss in baffle efficiency of the upper baffle is larger than the gain in the efficiency of the lower baffle. The damping decreases first with decreasing liquid surface. For a surface amplitude of the liquid at the tank wall of ζ_w = 0.01a, the minimum is located at 0.01a below the baffle. For ζ_w = 0.05a it is about 0.025a below the baffle and for ζ_w = 0.1a it is about 0.03a below the baffle.

For a larger value of the surface amplitude of 0.2a, the minimum is located 0.04a below the baffle; i.e., the smallest damping is obtained when the free fluid surface is by 0.04 tank radius below the baffle. For ζ_w = 0.5a, it is about 0.055a below the baffle. With further decreasing fluid height, the damping increases and reaches its maximum value for ζ_w = 0.01a at a liquid location of 0.01a above the baffle. This maximum value, for various surface amplitudes, is reached at various locations of the free surface. For ζ_w = 0.05a, the maximum of the damping is at 0.035a, for ζ_w = 0.1a, it is at about 0.042a, for ζ_w = 0.2a, it is at 0.02a, and for ζ_w = 0.5a, it is at 0.02a. From then on the damping factor decreases again with decreasing fluid height to the value at the baffle with which it started.

Figure 14 exhibits the same result for a constant baffle width and various free surface amplitudes versus the baffle location d/a. Figure 15 shows the damping factor γ_s versus the surface amplitude ζ_w/a for various liquid levels d and the widths w = 0.05a and w = 0.15a. The distance between baffles is again D = 0.2a, and there are ten baffles above and ten baffles below the free undisturbed fluid surface. Figure 16 exhibits the damping factor of these baffles versus their width w. Here the location of the free fluid surface is the parameter and the surface amplitude is ζ_w = 0.1a and ζ_w = 0.3a. The most important result of a multiple baffle arrangement is presented in Figure 17. For decreasing liquid

level to the left the damping factor is given for various baffle distances of D = 0.4a, 0.2a, 0.15a, 0.1a, 0.05a. The baffle width is considered to be w = 0.1a, and the surface amplitude is ζ_w = 0.1a and 0.2a. Counting from the abscissa zero, there are ten baffles above and ten baffles below the undisturbed fluid surface. With decreasing liquid surface the number of baffles below the surface decreases; therefore, the damping factor decreases. As could be expected, the damping factor is larger for smaller baffle distances. Doubling the distance between baffles presents only about half of the damping factor. The behavior of the damping factor between baffles exhibits the same result as that already presented in Figure 15. If the free undisturbed surface moves below the baffle, the damping decreases; i.e., the loss in contribution of the baffle above the fluid surface is stronger than the increase of the contribution of the baffle below the fluid surface. With decreasing height the latter contribution increases, thus increasing the damping factor, which from a certain level below the free fluid surface (at which the baffle has its maximum influence) decreases again. This is repeated.

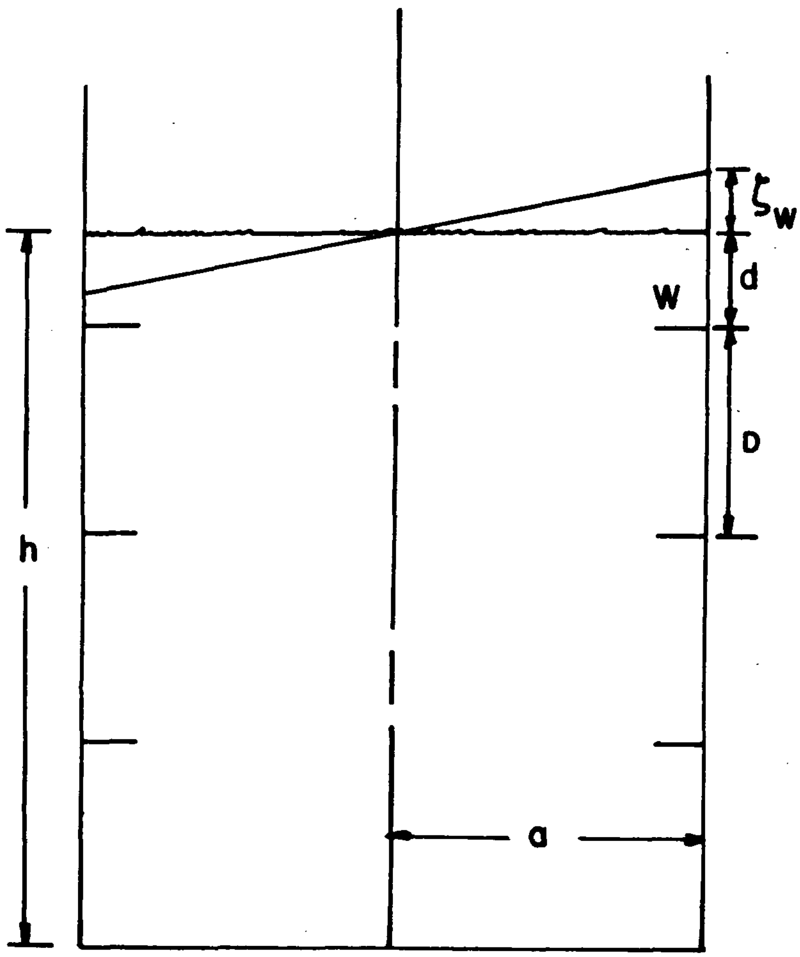
CONCLUSIONS

The damping of an annular flat ring baffle is determined with the inclusion of the effect that part of the baffle is, at a certain time, not subjected to the liquid during one slosh cycle. The results agree closely with measured damping factors except at the peak values, where, due to the turbulent nature of the fluid, considerable scatter occurs. The trend in this region shows, however, that the computed damping factor is always below the measured ones. Outside this maximum damping region, the agreement is very good. Miles' formula agrees closely with the measured results as long as the baffle is completely exposed to the liquid. In the region where actual maximum damping is obtained to the location where the baffle is placed in the free undisturbed fluid surface, Miles' formula expresses too high a damping. For a location of the baffle in the undisturbed liquid surface, Miles' formula results in a value more than twice the actual magnitude.

The influence of additional baffles and their spacing is quite important. Comparison of the damping factor of a single baffle with that of many baffles of distance D = 0.2a shows that the magnitude of damping factor is larger and can be maintained sufficiently large for all locations of the liquid between the baffles. The magnitude of the fluctuation of the damping factor between the baffles can be decreased by closer spacing. The damping factor is larger for a multi-baffle arrangement, since the sharp decrease in damping for a single baffle is made up by another baffle. The maximum damping is therefore larger than that of a single baffle and becomes increasingly larger with increasing

baffle width w. Decreasing the distance of the baffles by half results in approximately double the damping factor γ_s. It also is larger for larger surface amplitudes. Decreasing liquid level will decrease the damping slightly because of the decreasing number of baffles below the free liquid surface.

FIGURE 1



TANK CONFIGURATION AND BAFFLE ARRANGEMENT

FIGURE 2a

DAMPING FACTOR VERSUS BAFFLE DEPTH FOR LIQUID AMPLITUDE $\zeta_w = 0.01a$ WITH THE BAFFLE WIDTH AS A PARAMETER (MILES FORMULA)

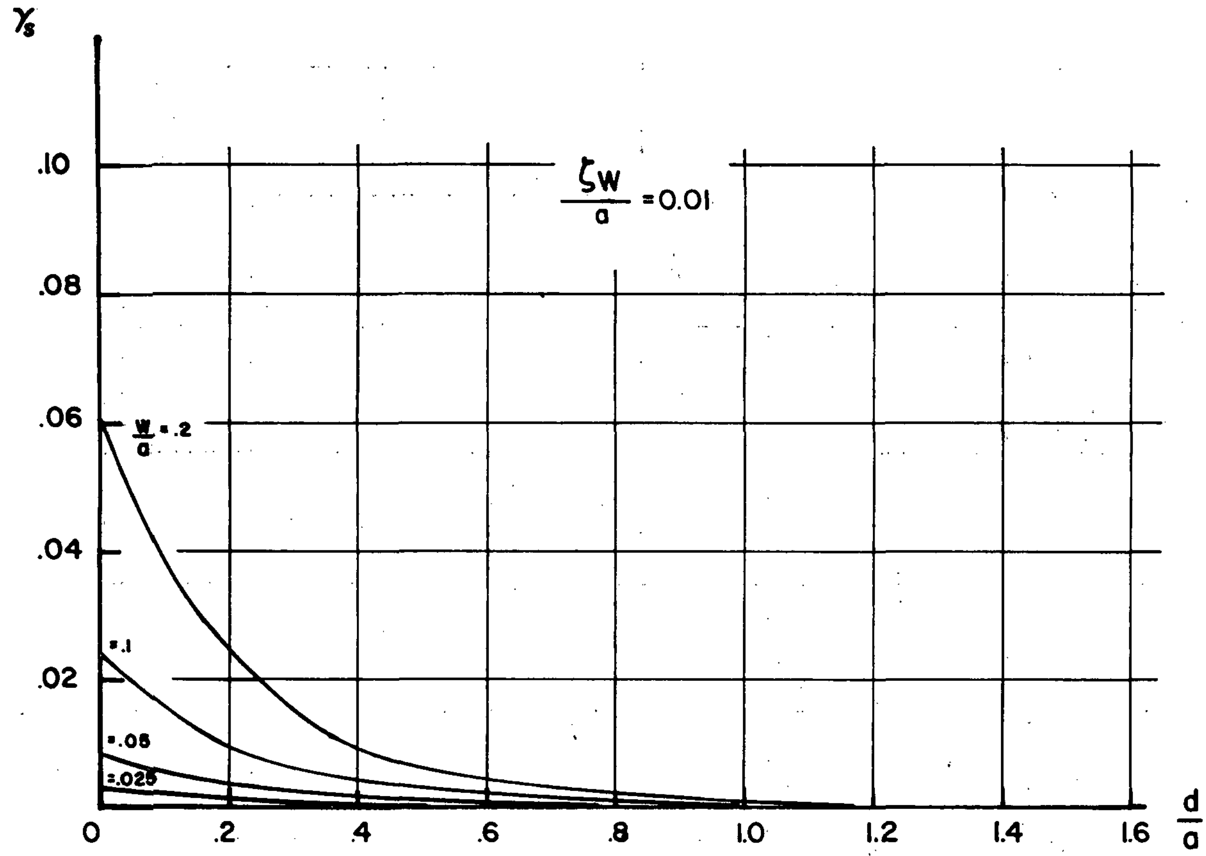


FIGURE 2b

DAMPING FACTOR VERSUS BAFFLE DEPTH FOR LIQUID AMPLITUDE ζ_w=0.05a WITH THE BAFFLE WIDTH AS A PARAMETER (MILES FORMULA)

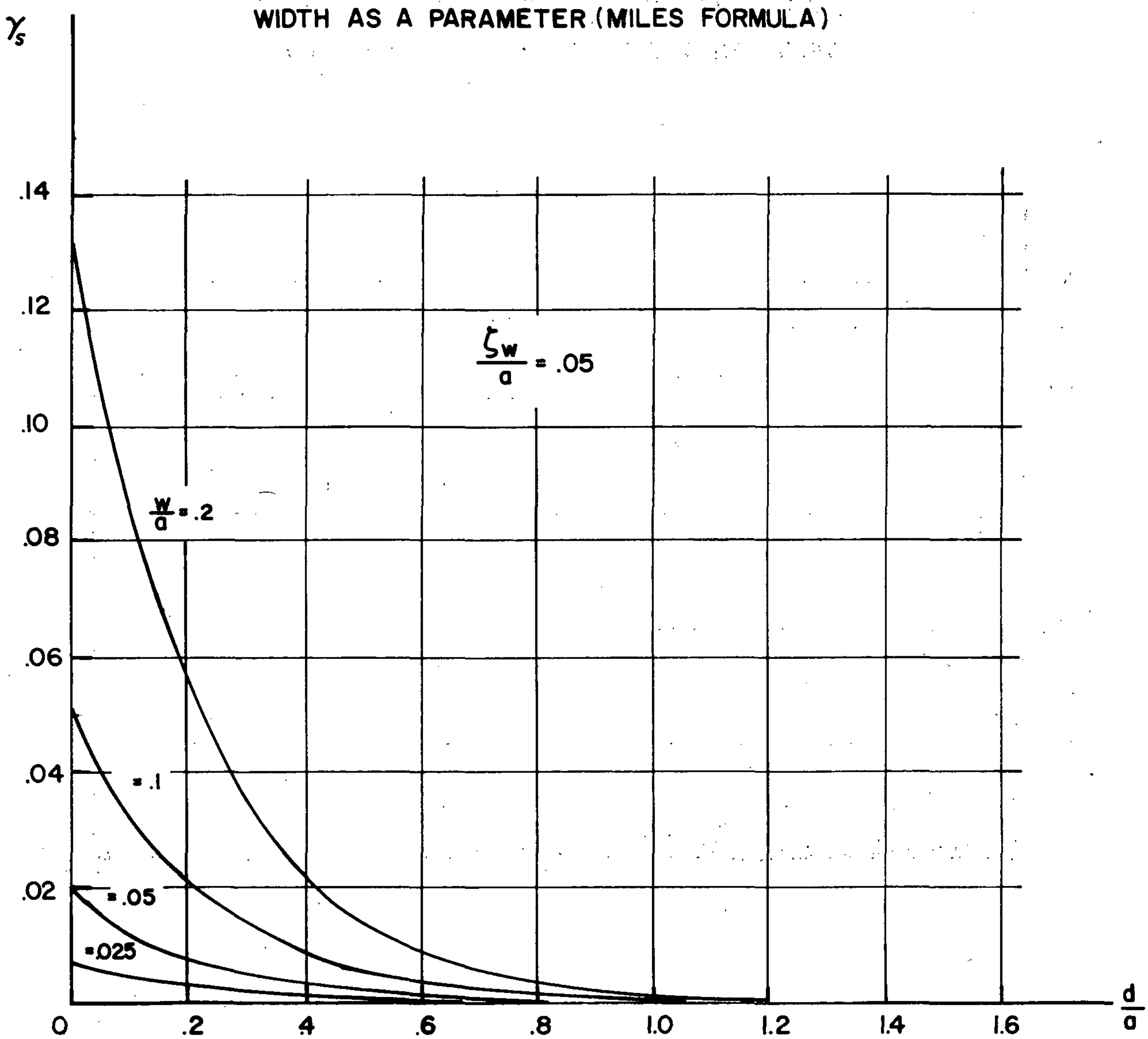


FIGURE 2c

DAMPING FACTOR VERSUS BAFFLE DEPTH FOR LIQUID AMPLITUDE $\zeta_w = 0.10a$ WITH THE BAFFLE WIDTH AS A PARAMETER (MILES FORMULA)

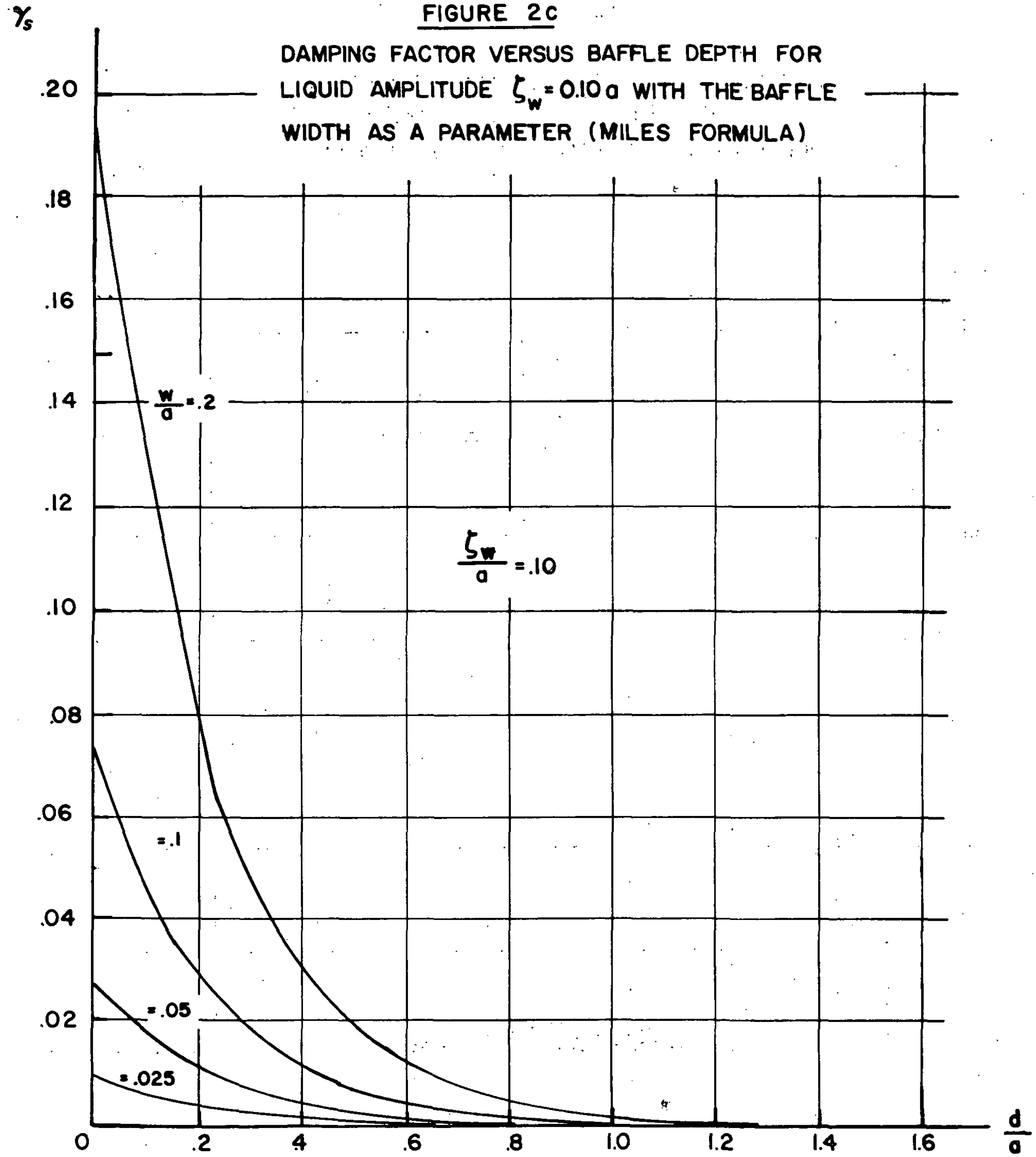


FIGURE 2d

DAMPING FACTOR VERSUS BAFFLE DEPTH FOR LIQUID AMPLITUDE $\zeta_w = .20a$ WITH THE BAFFLE WIDTH AS A PARAMETER (MILES FORMULA)

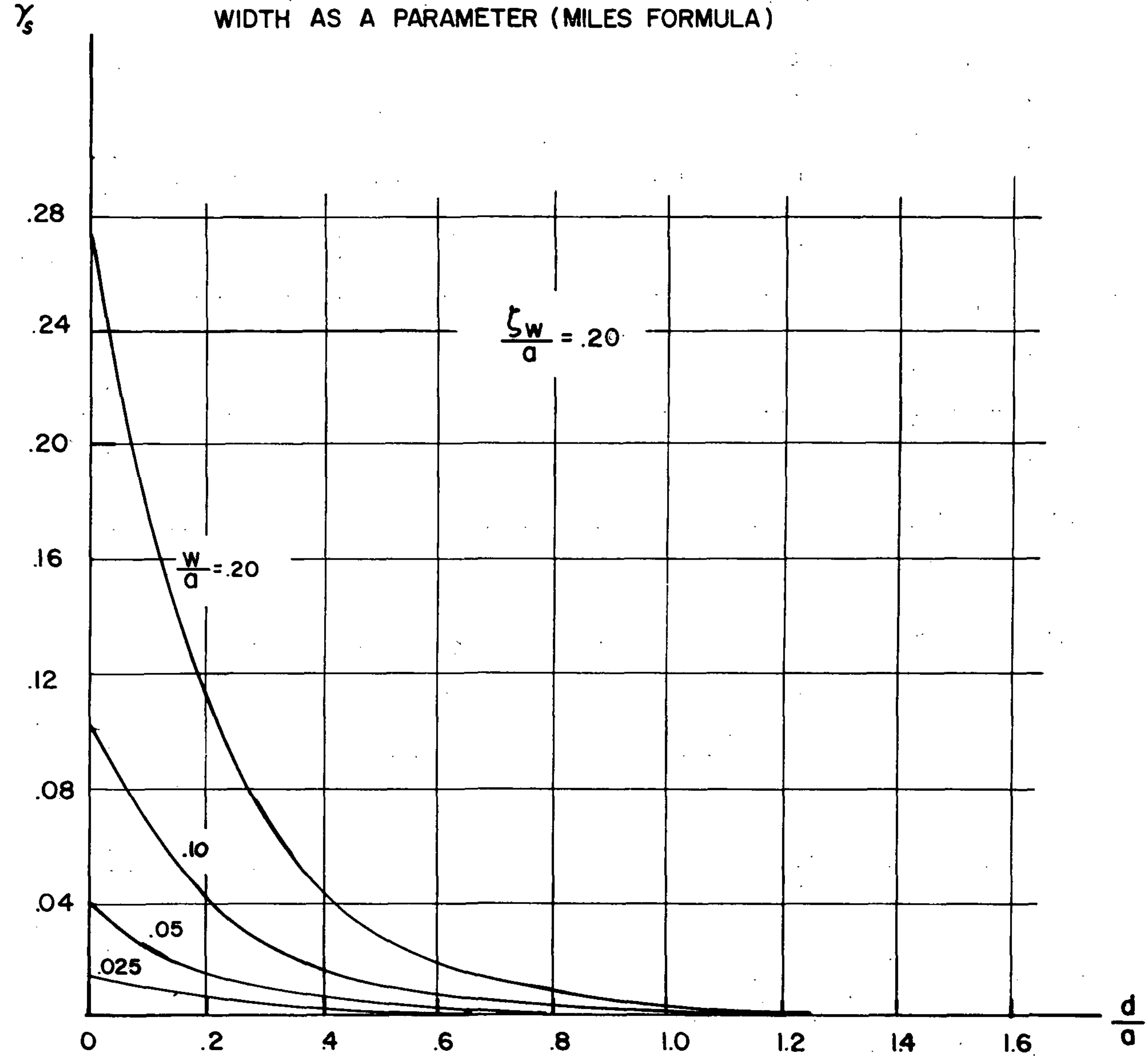


FIGURE 2e

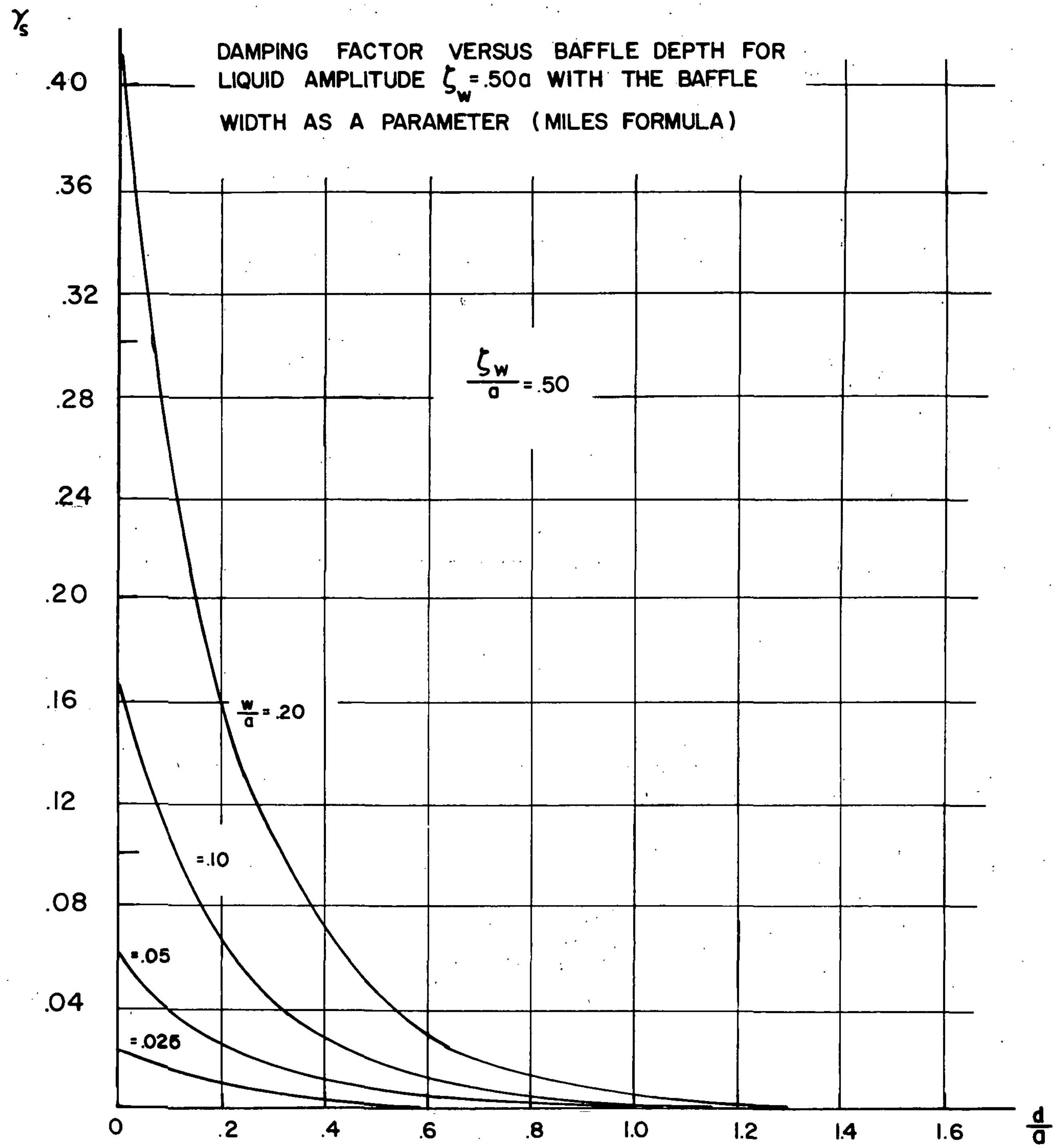

DAMPING FACTOR VERSUS BAFFLE DEPTH FOR LIQUID AMPLITUDE $\zeta_w = .50a$ WITH THE BAFFLE WIDTH AS A PARAMETER (MILES FORMULA)
γ_s
.40
.36
.32
.28
.24
.20
.16
.12
.08
.04
$\frac{\zeta_w}{a} = .50$
$\frac{w}{a} = .20$
= .10
= .05
= .025
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
$\frac{d}{a}$

FIGURE 3a

DAMPING FACTOR VERSUS BAFFLE DEPTH FOR WIDTH W=0.025 WITH LIQUID AMPLITUDE AS A PARAMETER (MILES FORMULA)

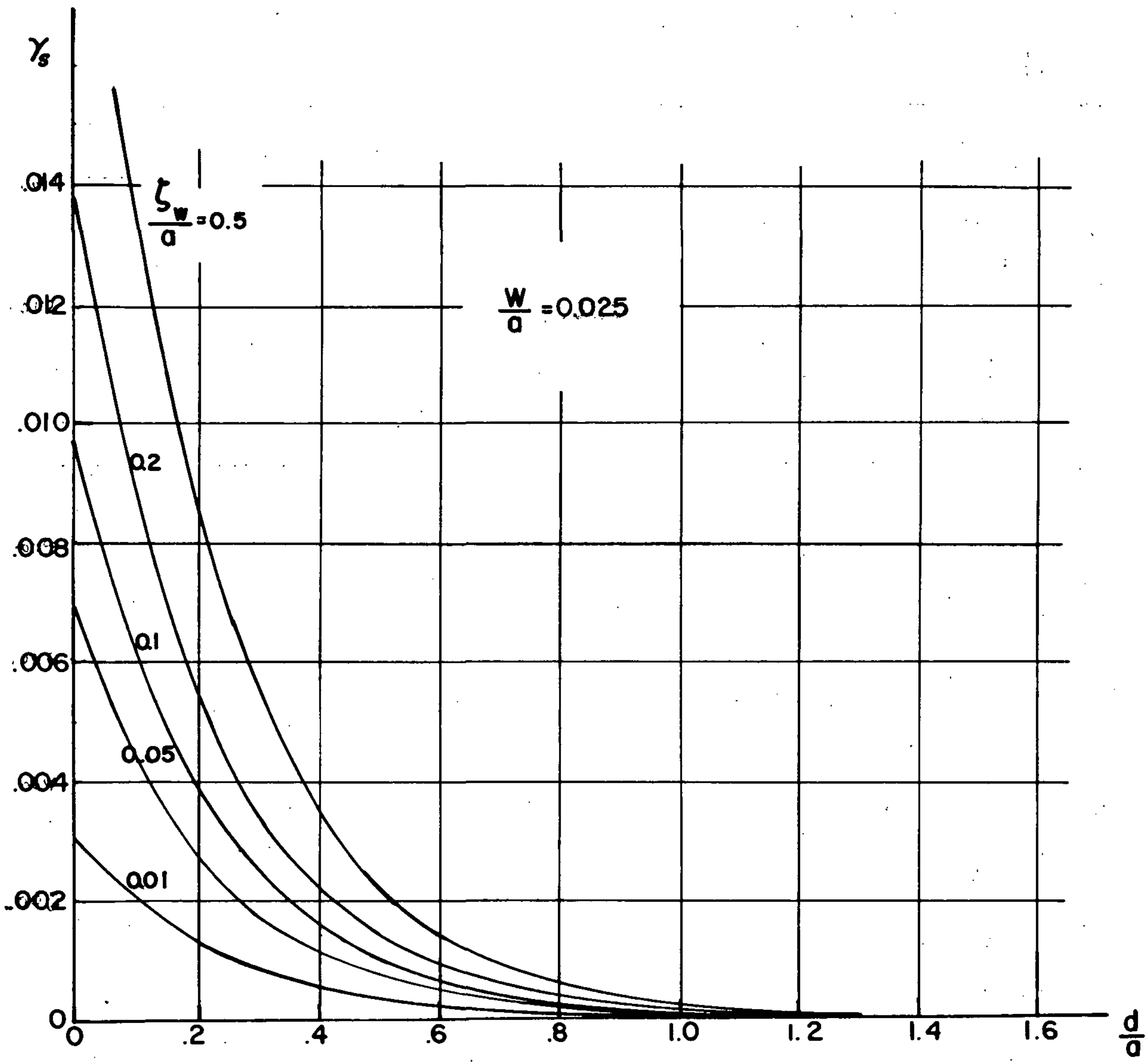


FIGURE 3b

DAMPING FACTOR VERSUS BAFFLE DEPTH FOR WIDTH W=0.05a WITH LIQUID AMPLITUDE AS A PARAMETER (MILES FORMULA)

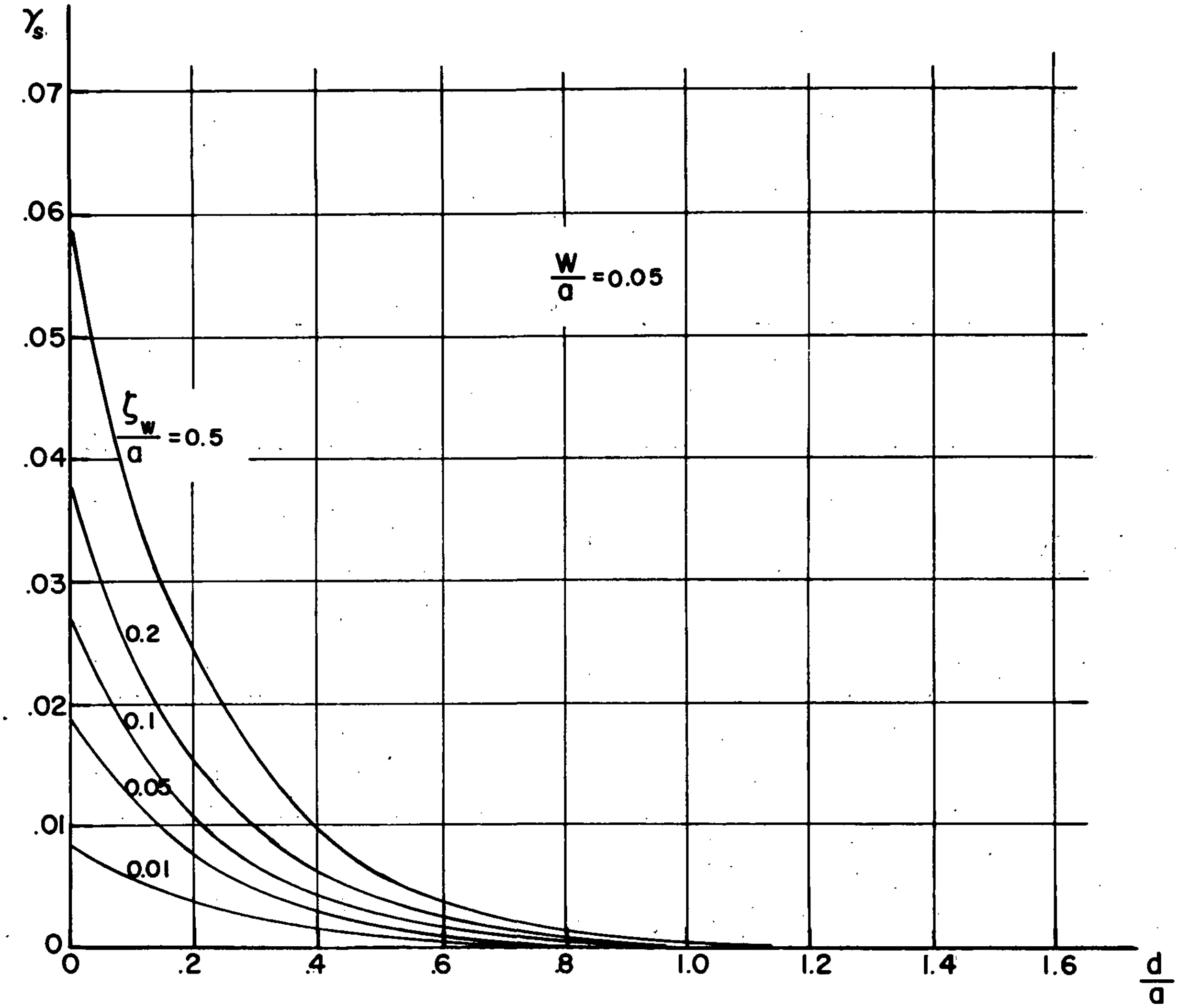


FIGURE 3c

DAMPING FACTOR VERSUS BAFFLE DEPTH FOR WIDTH W=0.10a WITH LIQUID AMPLITUDE AS A PARAMETER (MILES FORMULA)

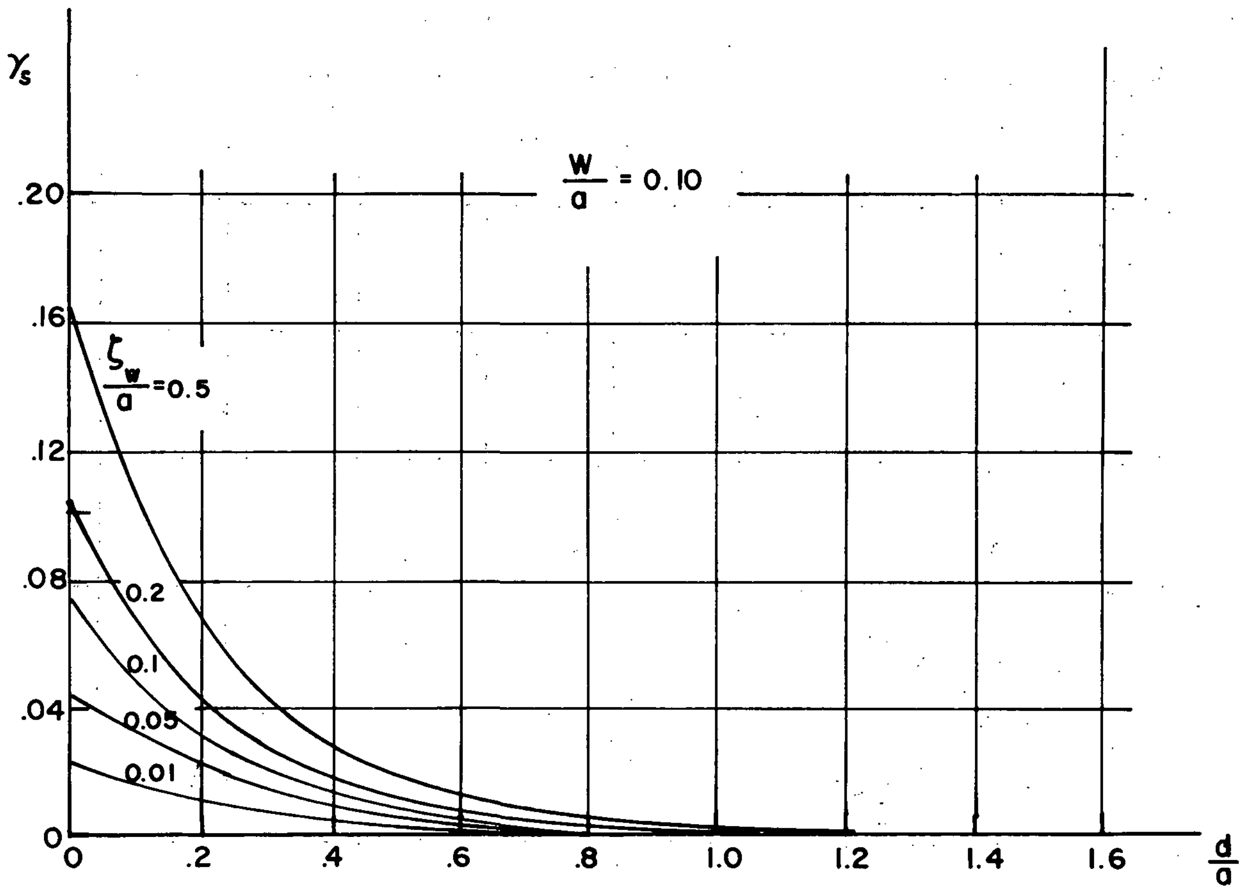


FIGURE 3 d

DAMPING FACTOR VERSUS BAFFLE DEPTH FOR WIDTH W = 0.20 a WITH LIQUID AMPLITUDE AS A PARAMETER (MILES FORMULA)

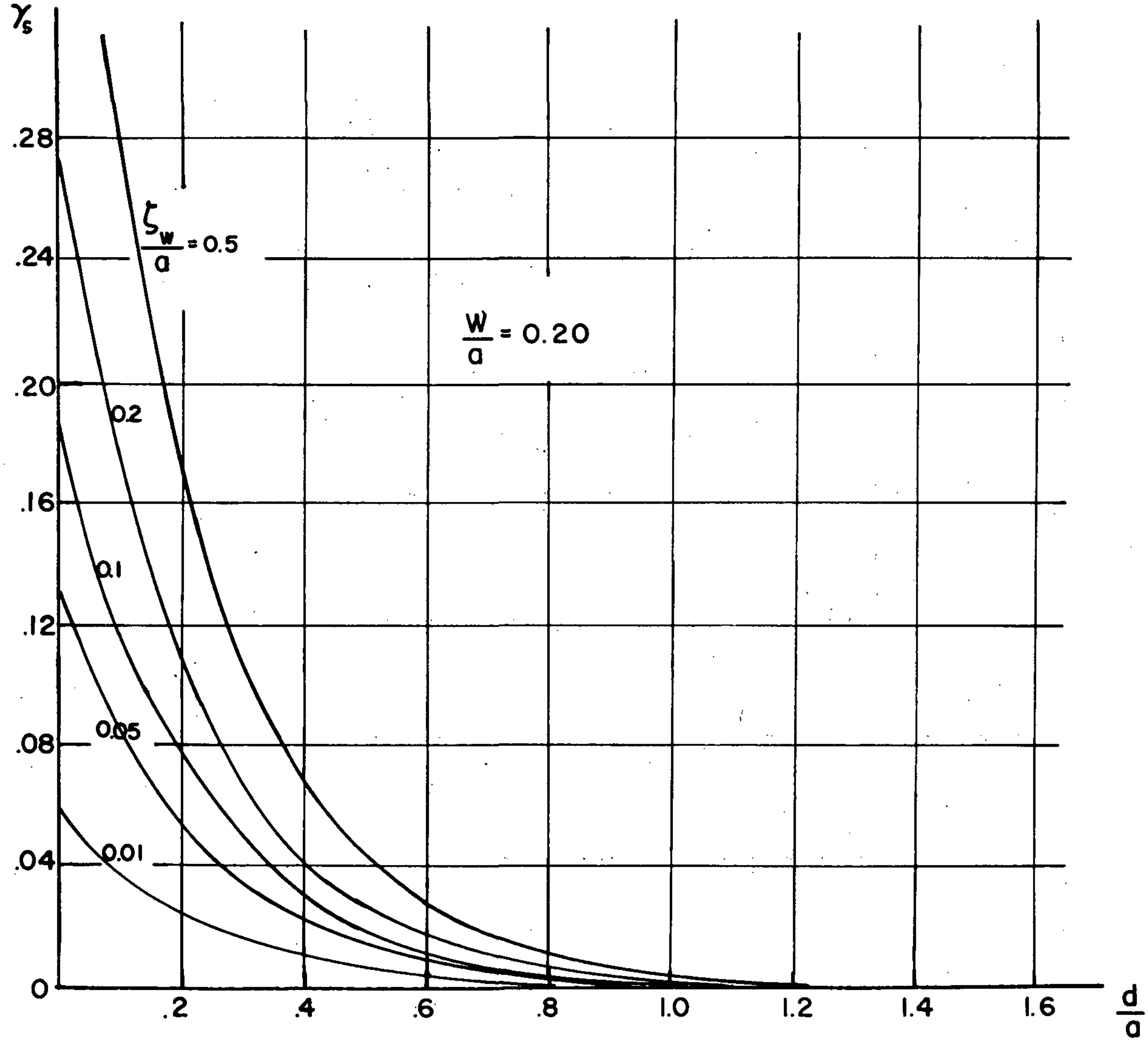


FIG. 4a

DAMPING FACTOR VERSUS SURFACE AMPLITUDE FOR BAFFLE WIDTH W=.05a WITH BAFFLE LOCATION AS A PARAMETER (MILES FORMULA)

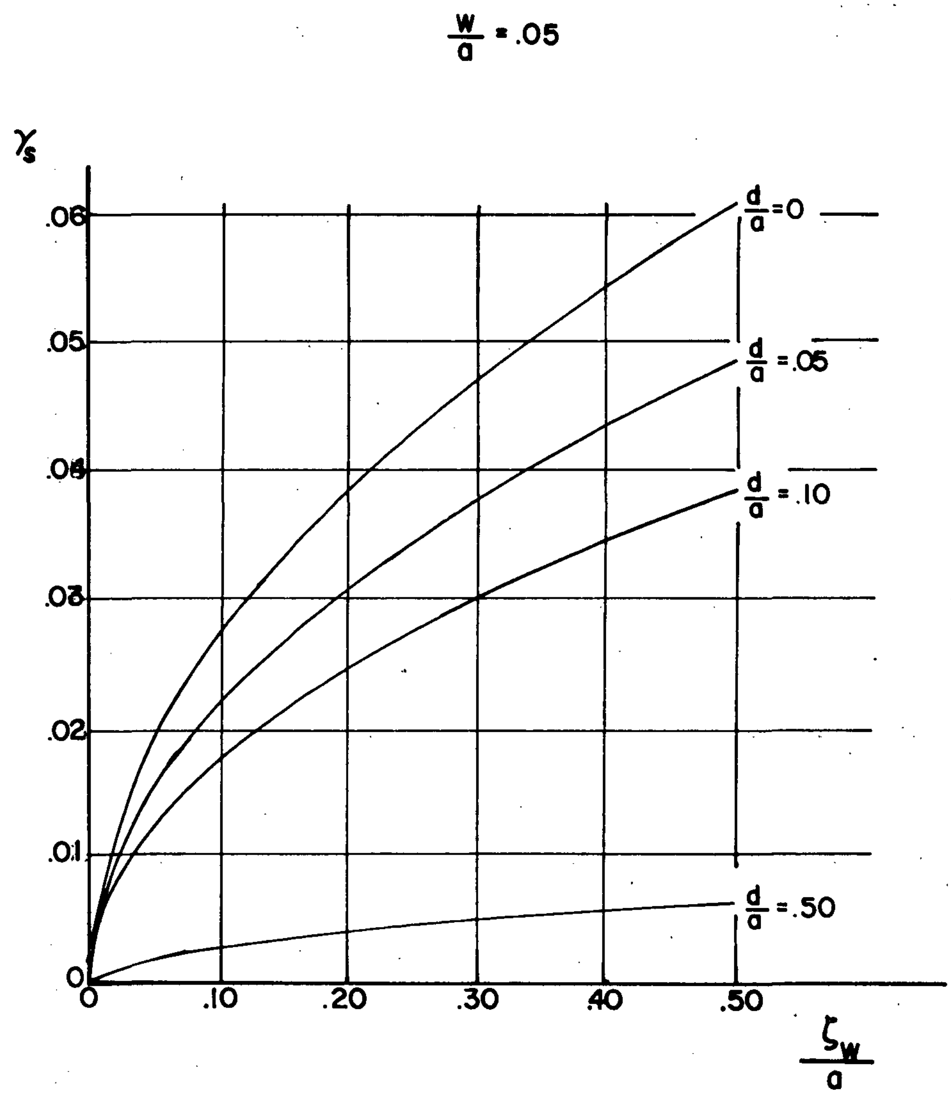


FIG. 4b

DAMPING FACTOR VERSUS SURFACE AMPLITUDE FOR BAFFLE WIDTH W=.15a WITH BAFFLE LOCATION AS A PARAMETER (MILES FORMULA)

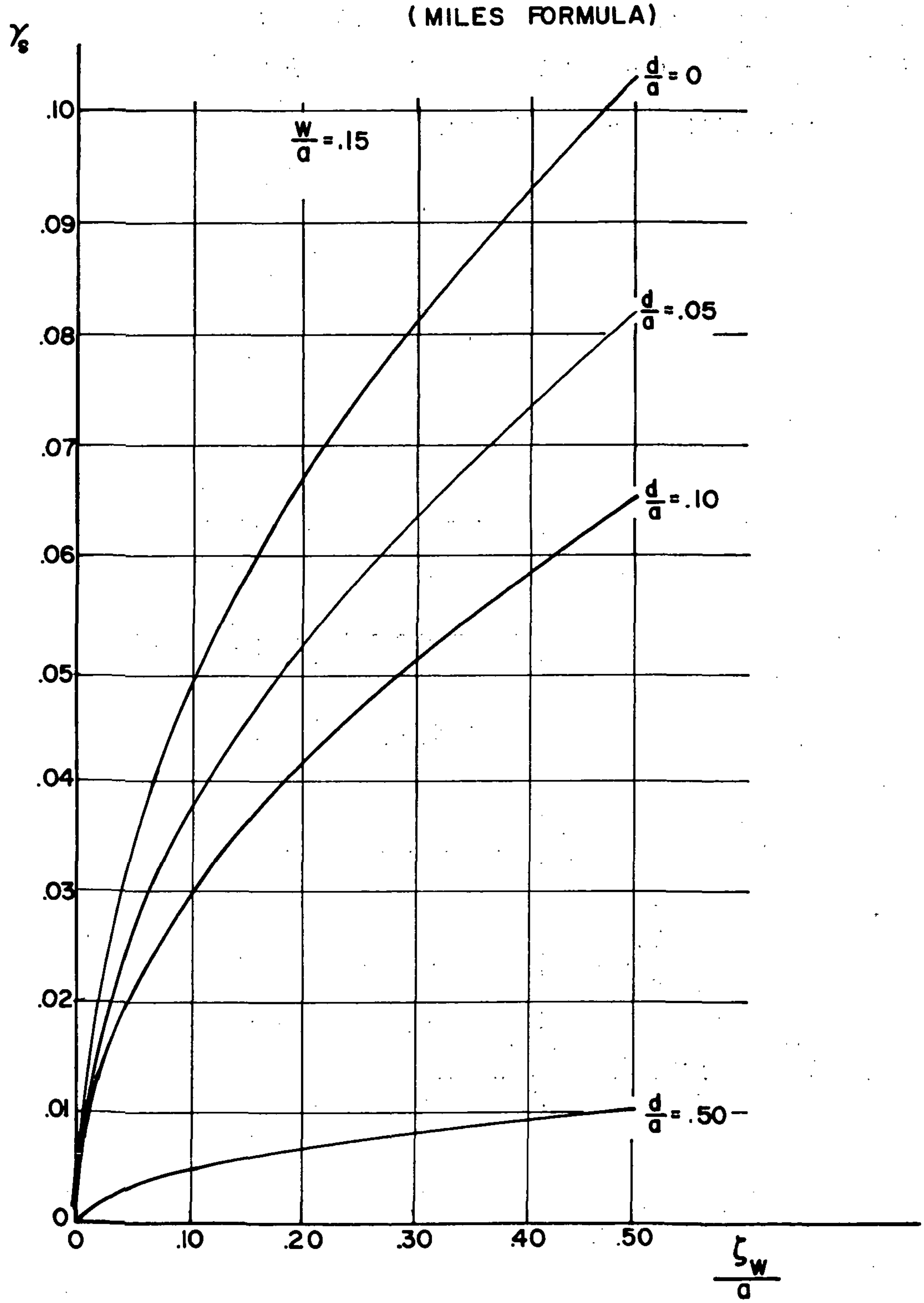


FIG. 5a

DAMPING FACTOR VERSUS BAFFLE WIDTH FOR $\zeta_W = .10a$ WITH LOCATION OF BAFFLE AS A PARAMETER (MILES FORMULA)

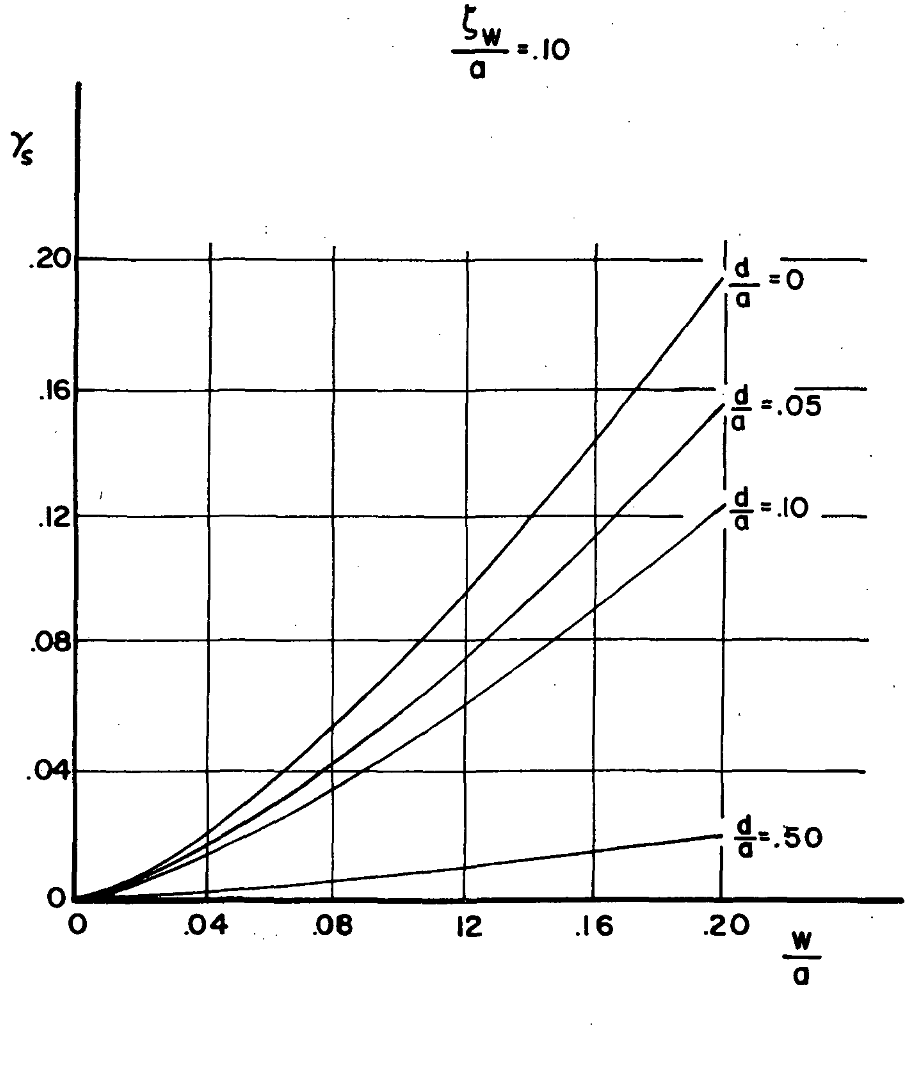


FIG. 5b

DAMPING FACTOR VERSUS BAFFLE WIDTH FOR $\zeta_W = .30a$ WITH LOCATION OF BAFFLE AS A PARAMETER (MILES FORMULA)

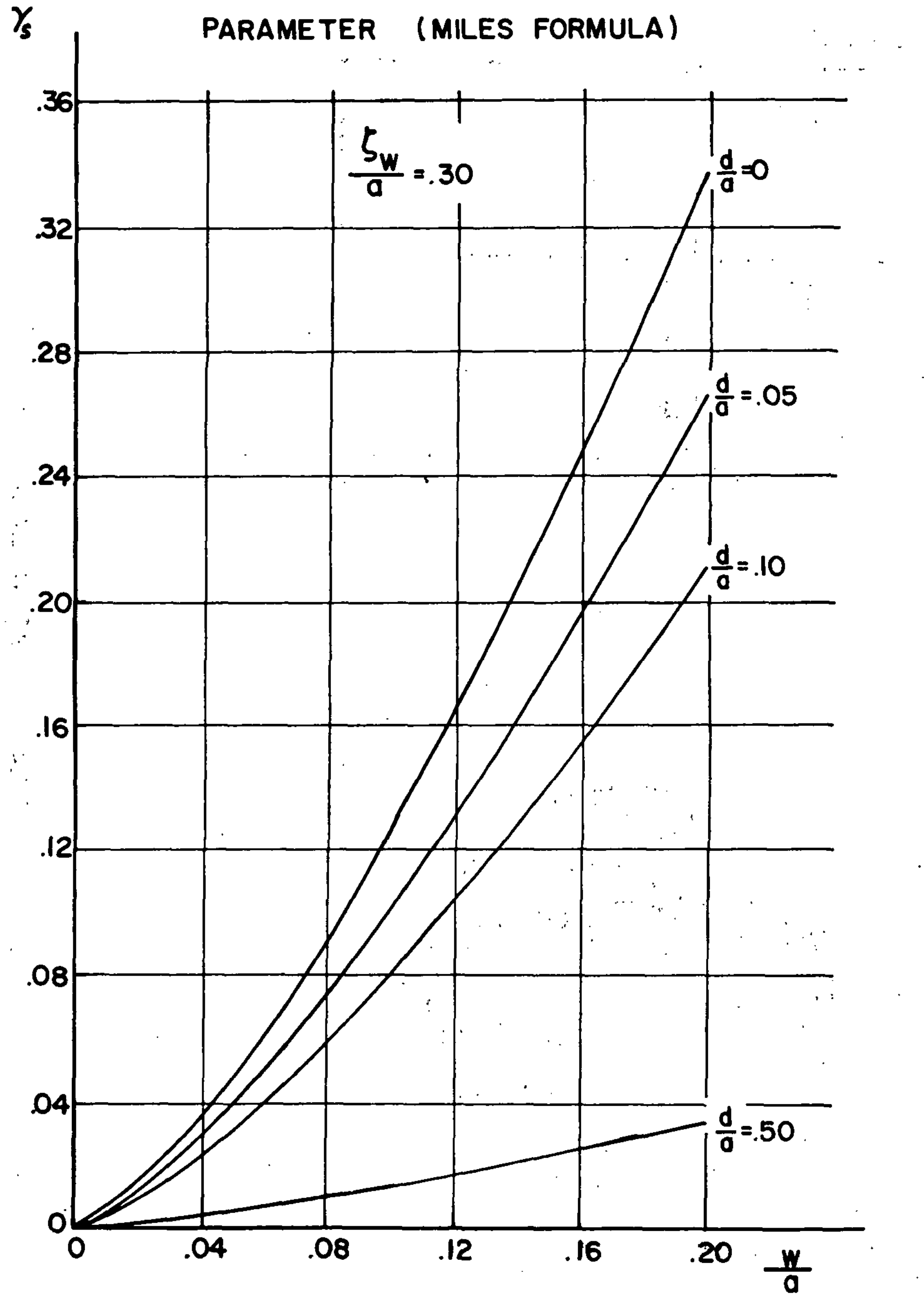
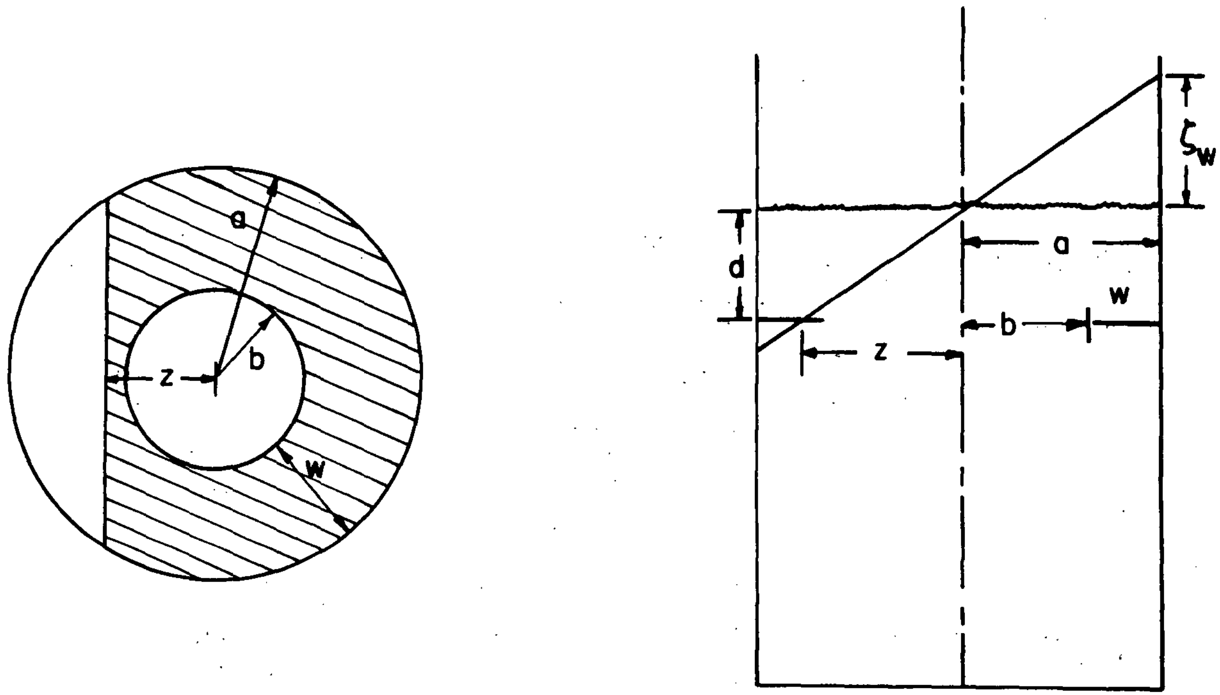


FIGURE 6



ANNULAR RING BAFFLE PARTIALLY OUT OF LIQUID
DURING SLOSH CYCLE

FIG. 7a

EFFECTIVE BAFFLE AREA VERSUS BAFFLE DEPTH d FOR LIQUID AMPLITUDE $\zeta_w = 0.5a$ AND VARIOUS BAFFLE WIDTH W

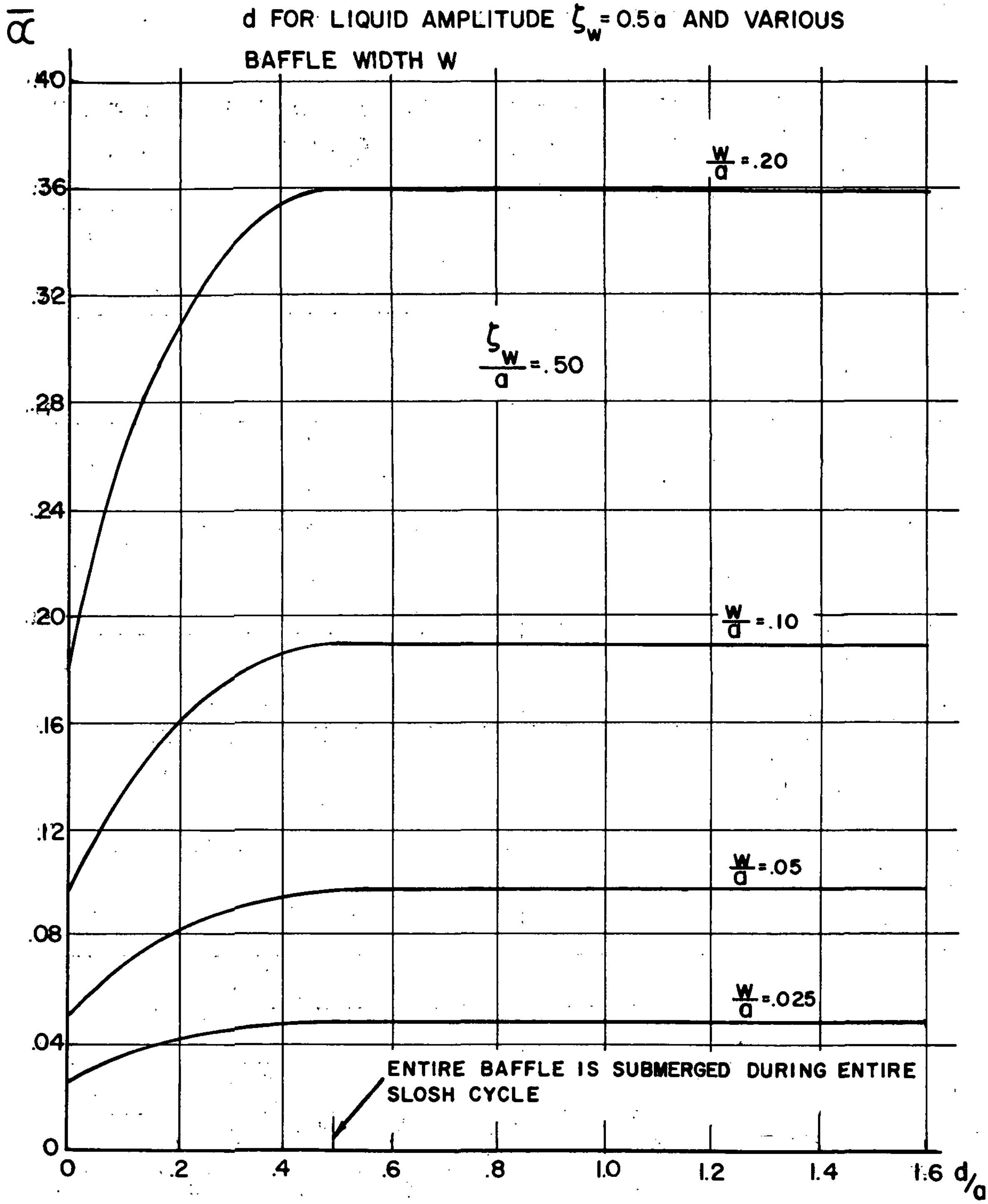


FIG. 7b

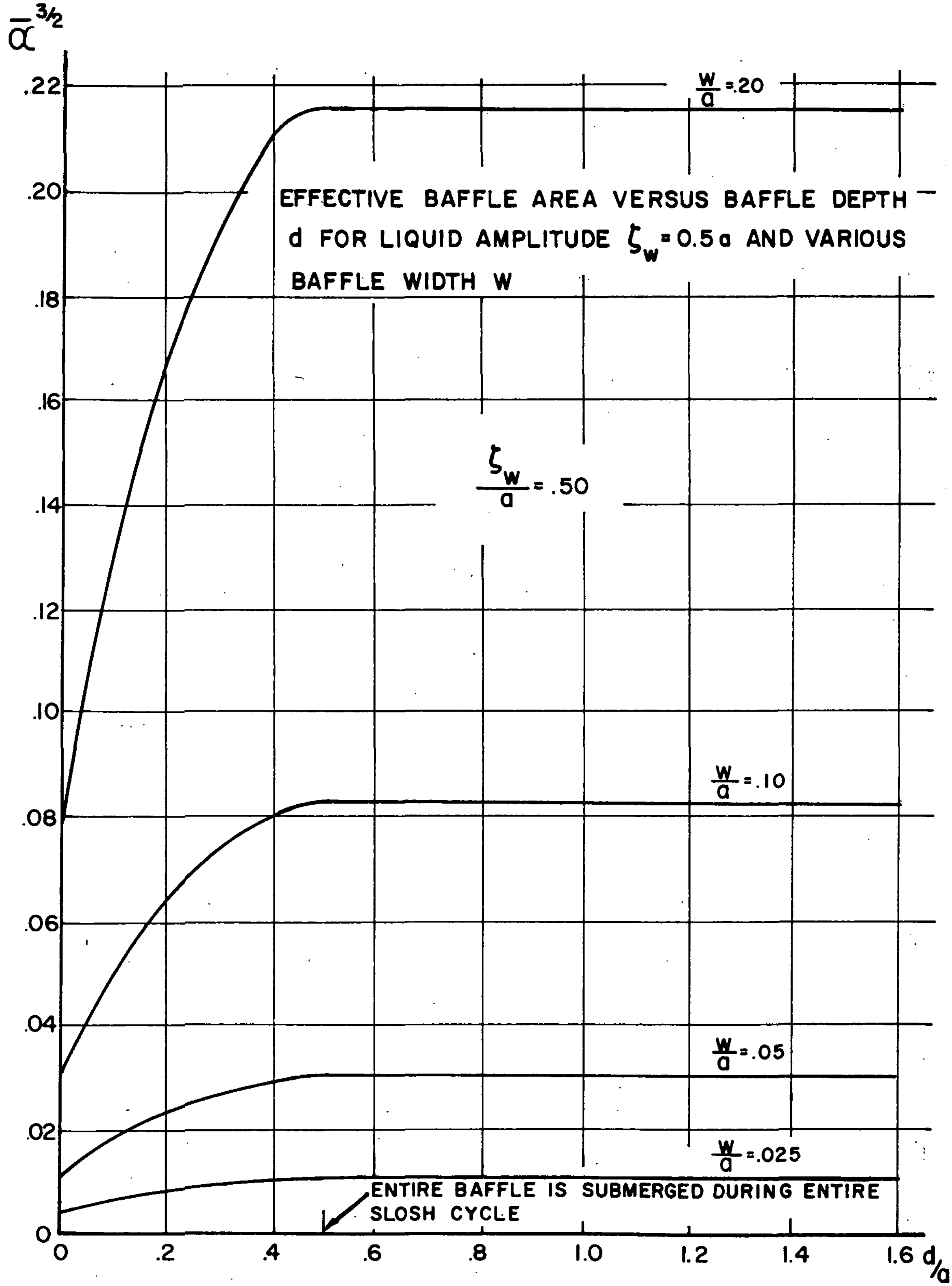

$\bar{\alpha}^{3/2}$
.22
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
0
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
d/a
$\frac{w}{a} = .20$
EFFECTIVE BAFFLE AREA VERSUS BAFFLE DEPTH d FOR LIQUID AMPLITUDE $\zeta_w = 0.5a$ AND VARIOUS BAFFLE WIDTH W
$\frac{\zeta_w}{a} = .50$
$\frac{w}{a} = .10$
$\frac{w}{a} = .05$
$\frac{w}{a} = .025$
ENTIRE BAFFLE IS SUBMERGED DURING ENTIRE SLOSH CYCLE

FIG. 8 a

EFFECTIVE BAFFLE AREA VERSUS BAFFLE DEPTH d FOR CONSTANT BAFFLE WIDTH W=0.1a AND VARIOUS SURFACE AMPLITUDE ζ_w

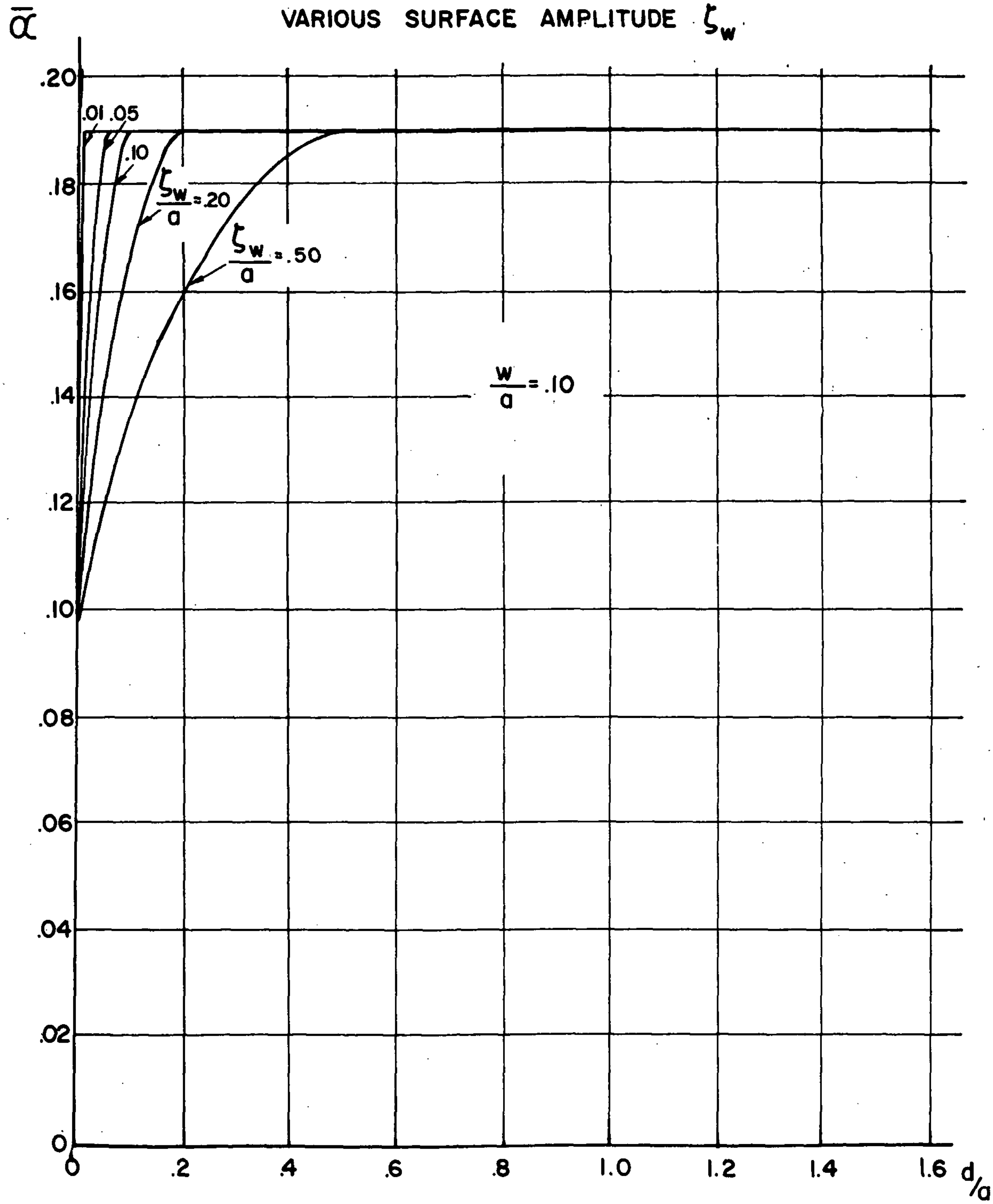


FIG. 8 b

EFFECTIVE BAFFLE AREA VERSUS BAFFLE DEPTH d FOR CONSTANT BAFFLE WIDTH W=0.1a AND VARIOUS SURFACE AMPLITUDE ζ_w

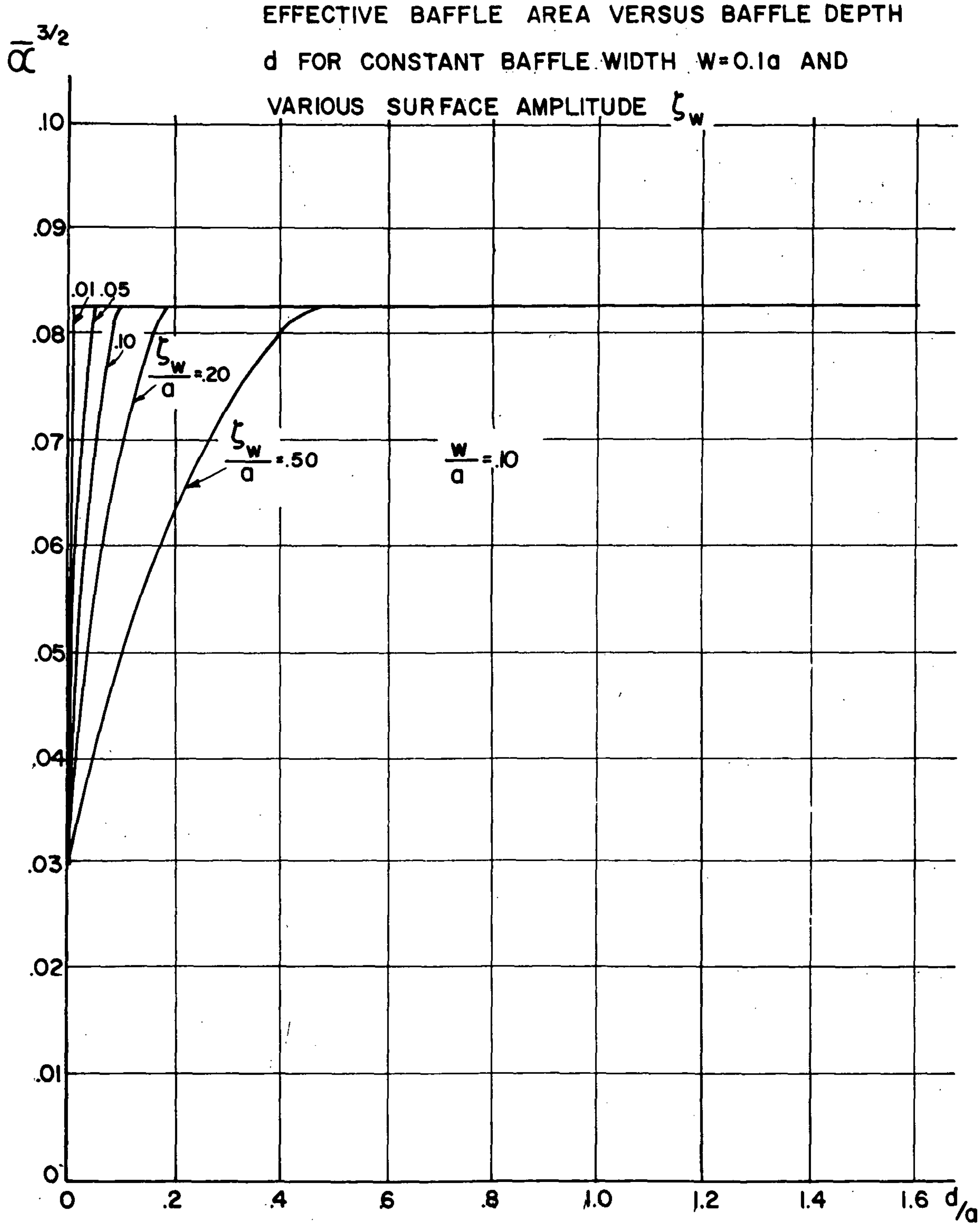


FIG. 9 a

DAMPING FACTOR VERSUS BAFFLE DEPTH FOR LIQUID AMPLITUDE $\zeta_w = 0.01a$ WITH THE BAFFLE WIDTH AS A PARAMETER (MILES FORMULA)

REVISED

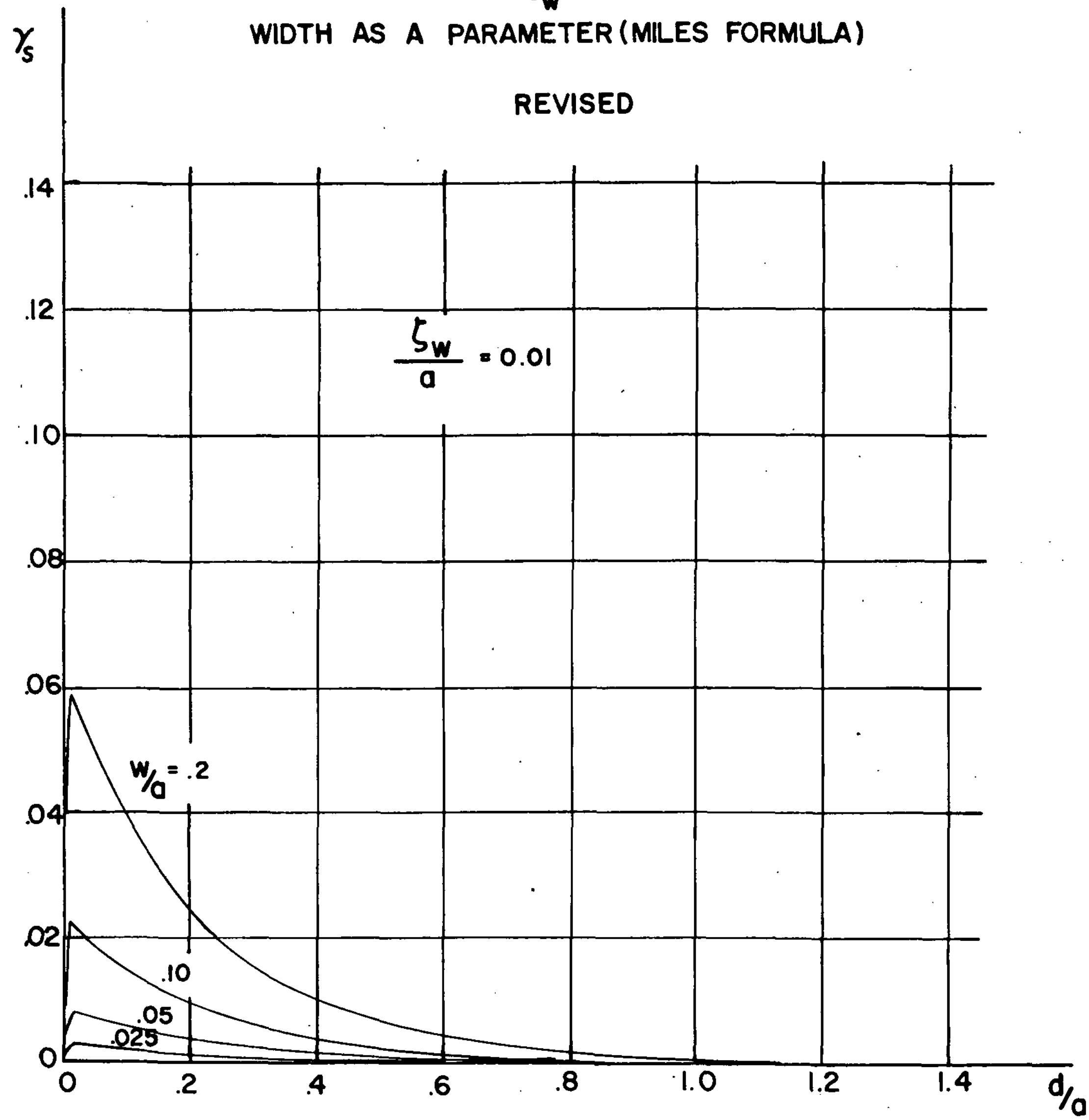


FIG. 9 b

DAMPING FACTOR VERSUS BAFFLE DEPTH FOR LIQUID AMPLITUDE $\zeta_w = 0.05a$ WITH THE BAFFLE WIDTH AS A PARAMETER (MILES FORMULA)
REVISED

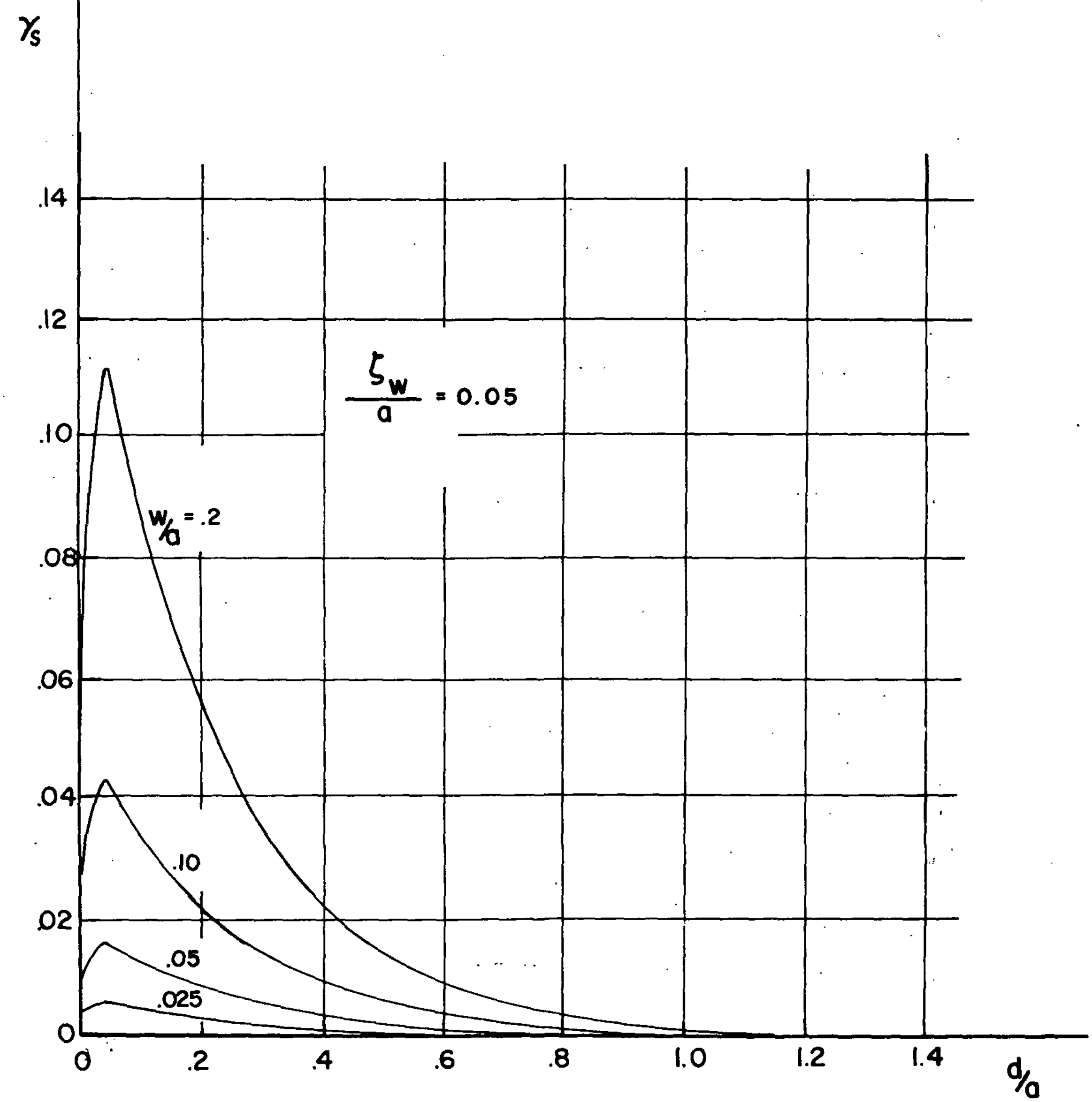


FIG. 9 c

DAMPING FACTOR VERSUS BAFFLE DEPTH FOR LIQUID AMPLITUDE $\zeta_w = 0.10a$ WITH THE BAFFLE WIDTH AS A PARAMETER (MILES FORMULA)

REVISED

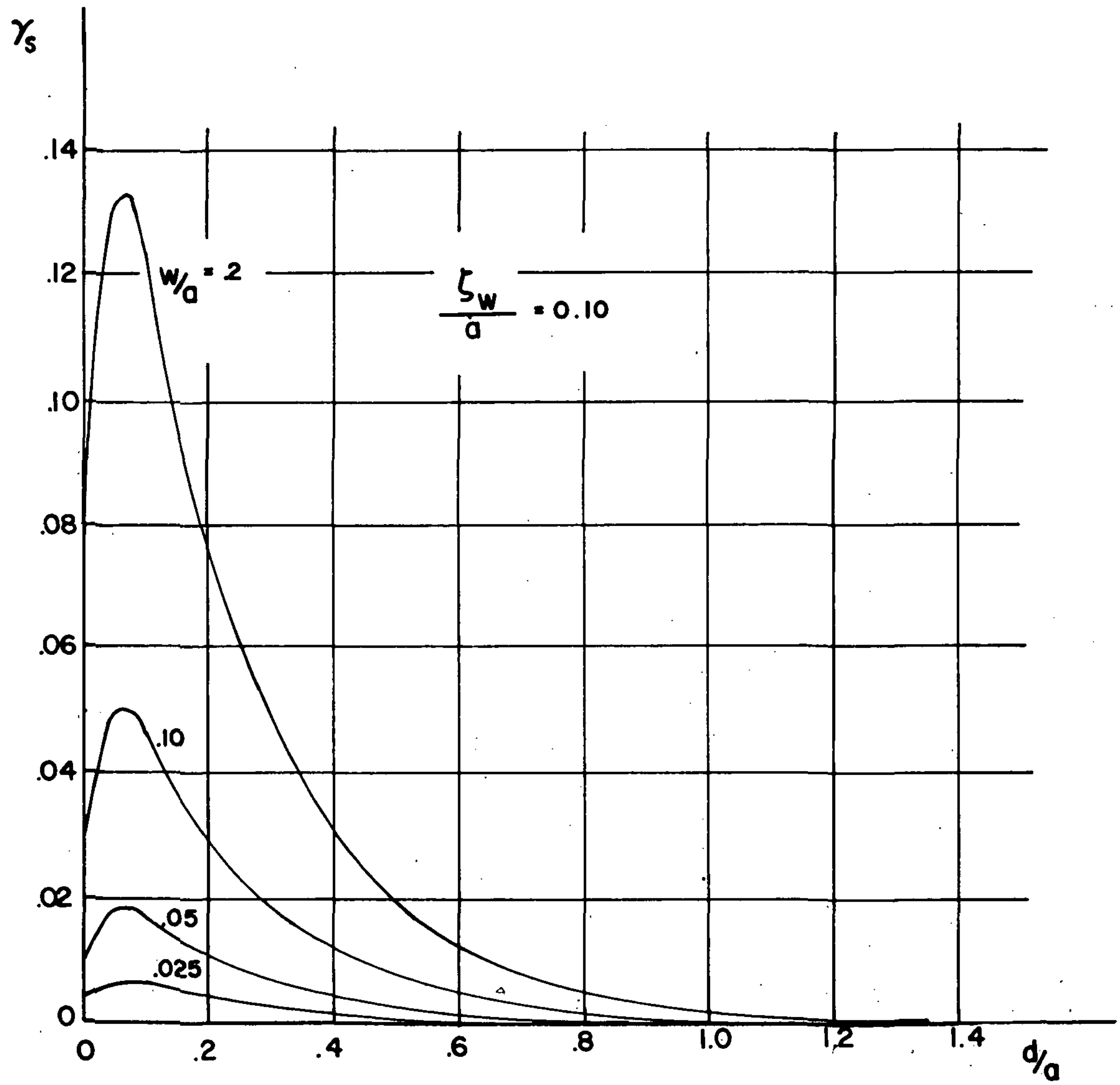


FIG. 9 d

DAMPING FACTOR VERSUS BAFFLE DEPTH FOR LIQUID AMPLITUDE ζ_w=0.20a WITH THE BAFFLE WIDTH AS A PARAMETER (MILES FORMULA) REVISED

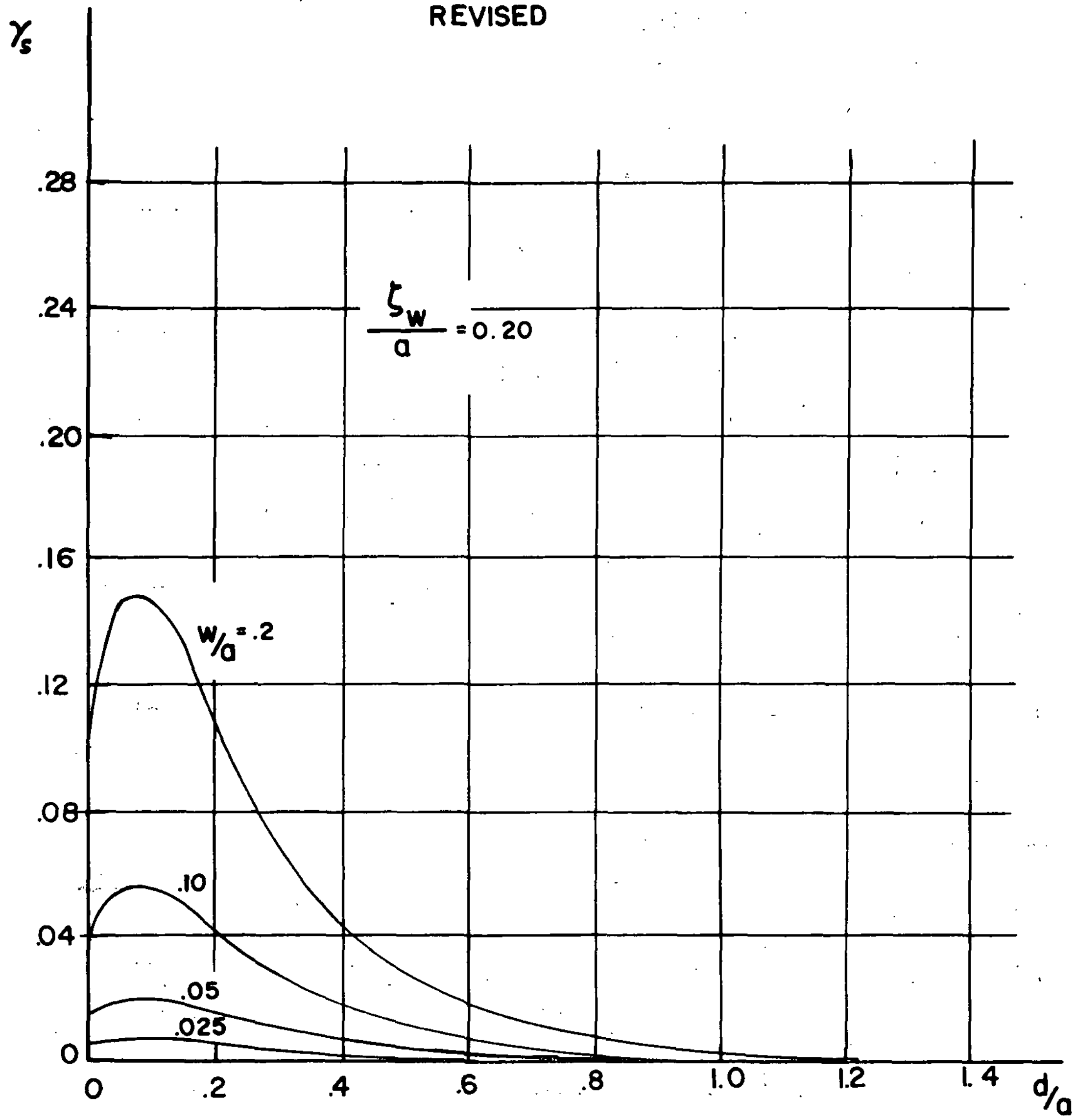


FIG. 9 e

DAMPING FACTOR VERSUS BAFFLE DEPTH FOR LIQUID AMPLITUDE $\zeta_w = 0.50a$ WITH THE BAFFLE WIDTH AS A PARAMETER (MILES FORMULA)

REVISED

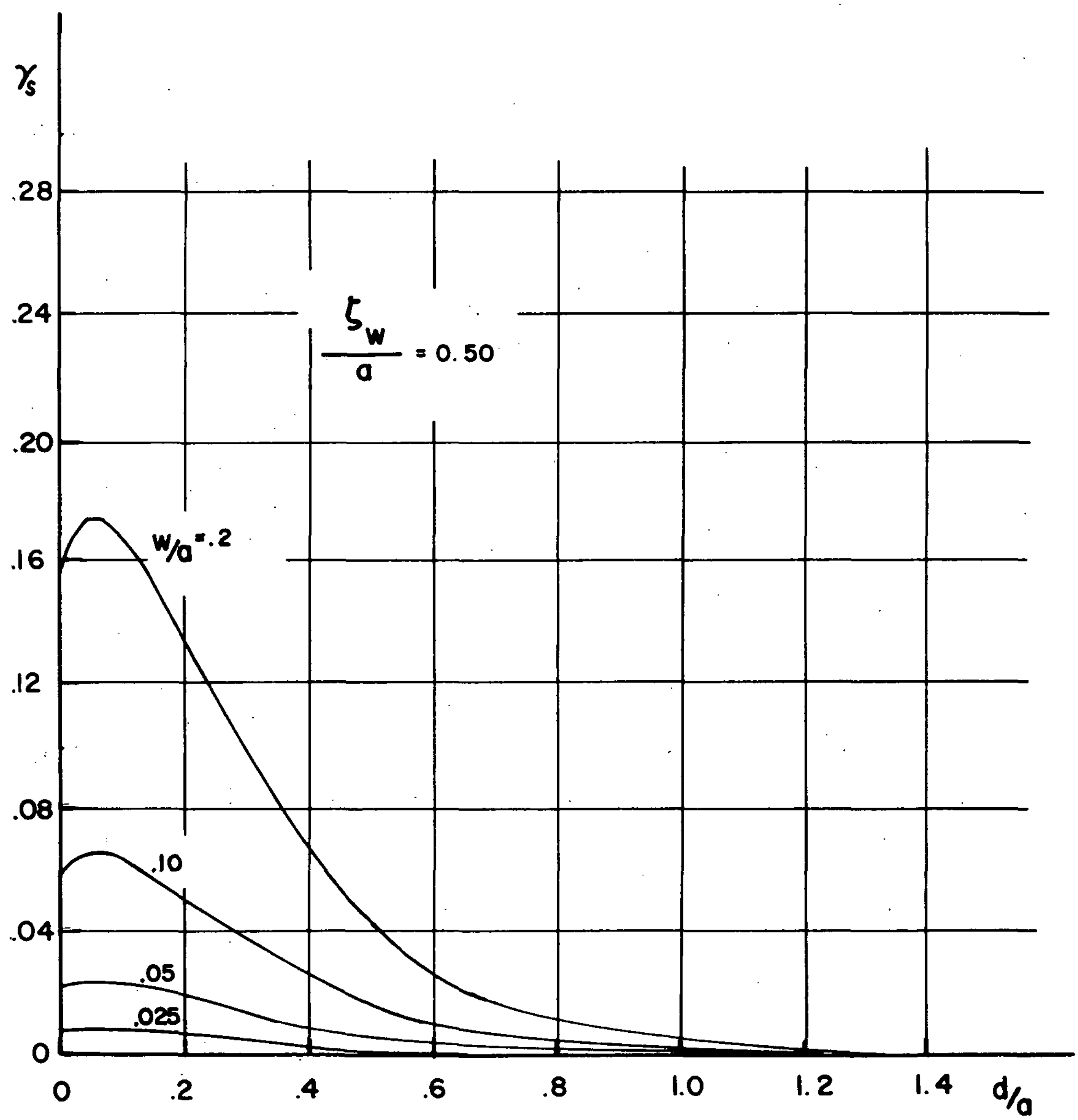


FIG. 10 a

DAMPING FACTOR VERSUS BAFFLE DEPTH FOR WIDTH W=0.025a WITH LIQUID AMPLITUDE AS A PARAMETER (MILES FORMULA)

REVISED

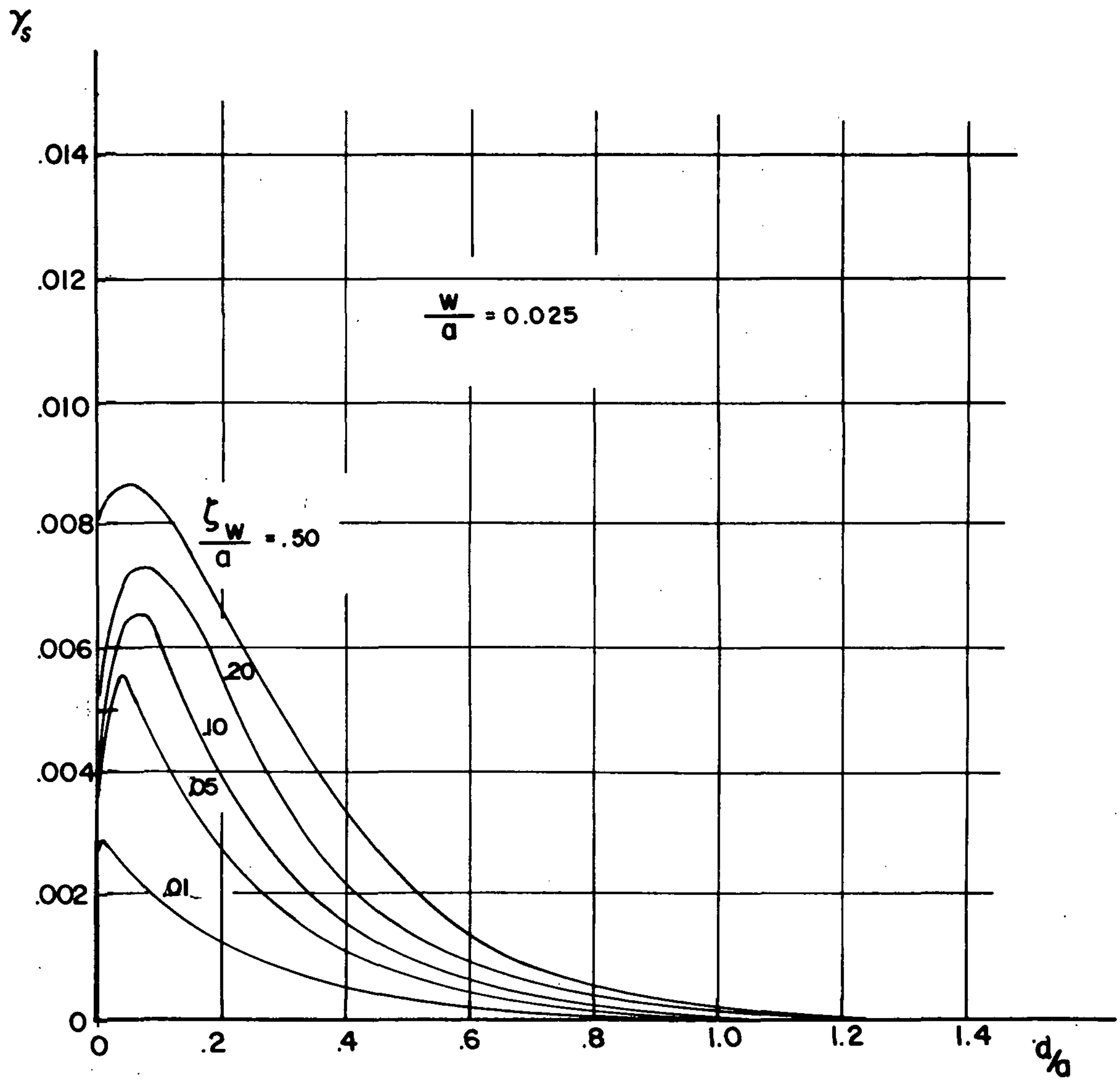


FIG. 10b

DAMPING FACTOR VERSUS BAFFLE DEPTH FOR WIDTH W = 0.05a WITH LIQUID AMPLITUDE AS A PARAMETER (MILES FORMULA)

REVISED

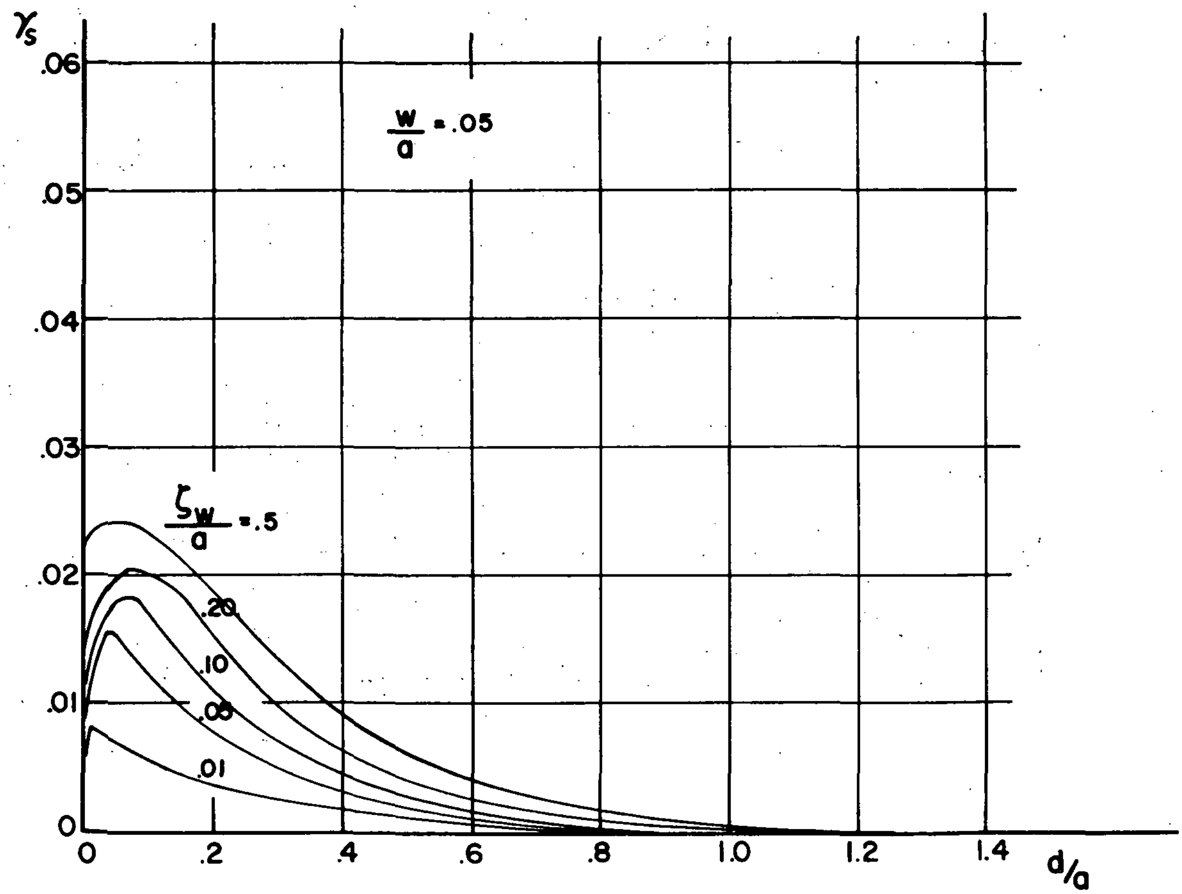


FIG. 10 c

DAMPING FACTOR VERSUS BAFFLE DEPTH FOR WIDTH W=.10a WITH LIQUID AMPLITUDE AS A PARAMETER (MILES FORMULA)

REVISED

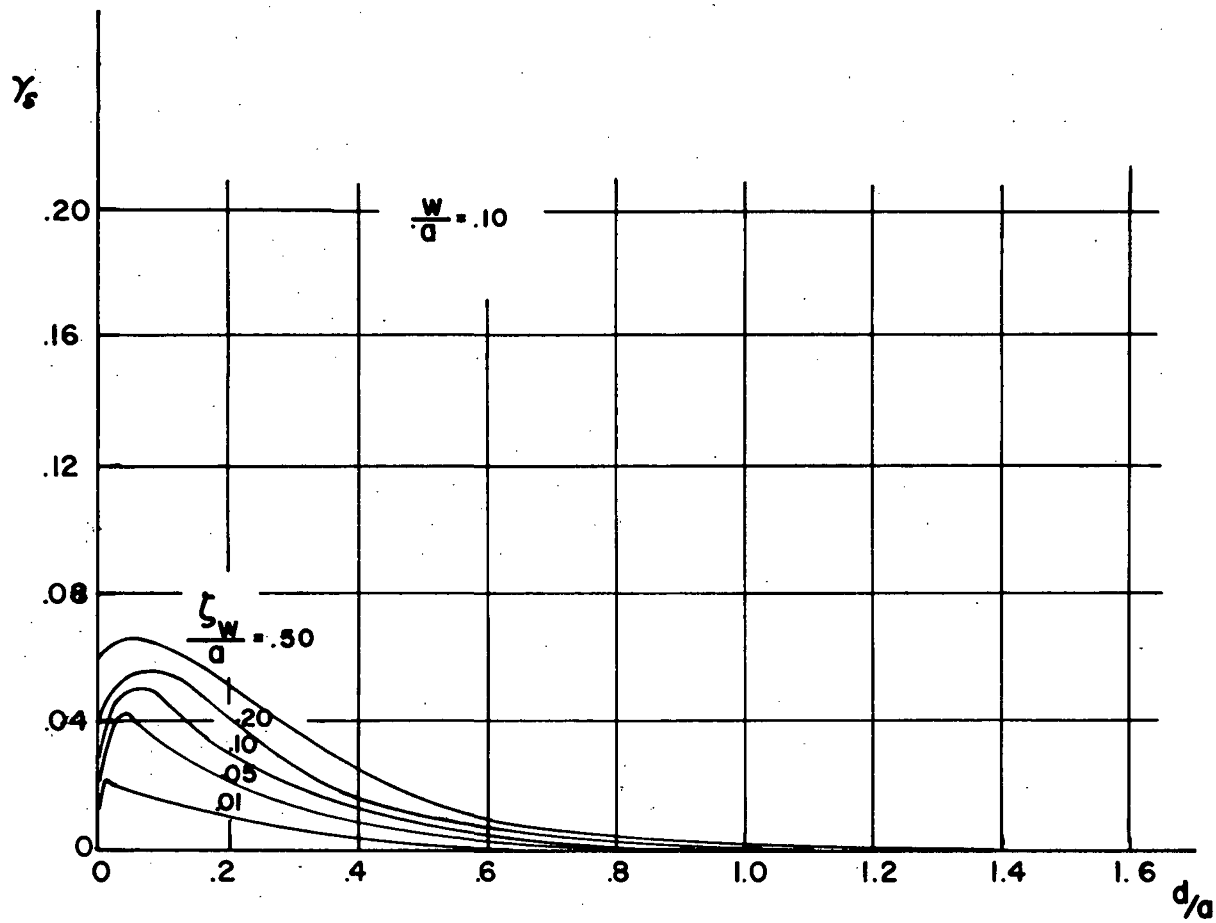


FIG. 10d

DAMPING FACTOR VERSUS BAFFLE DEPTH FOR WIDTH W=0.20a WITH LIQUID AMPLITUDE AS A PARAMETER (MILES FORMULA)

REVISED

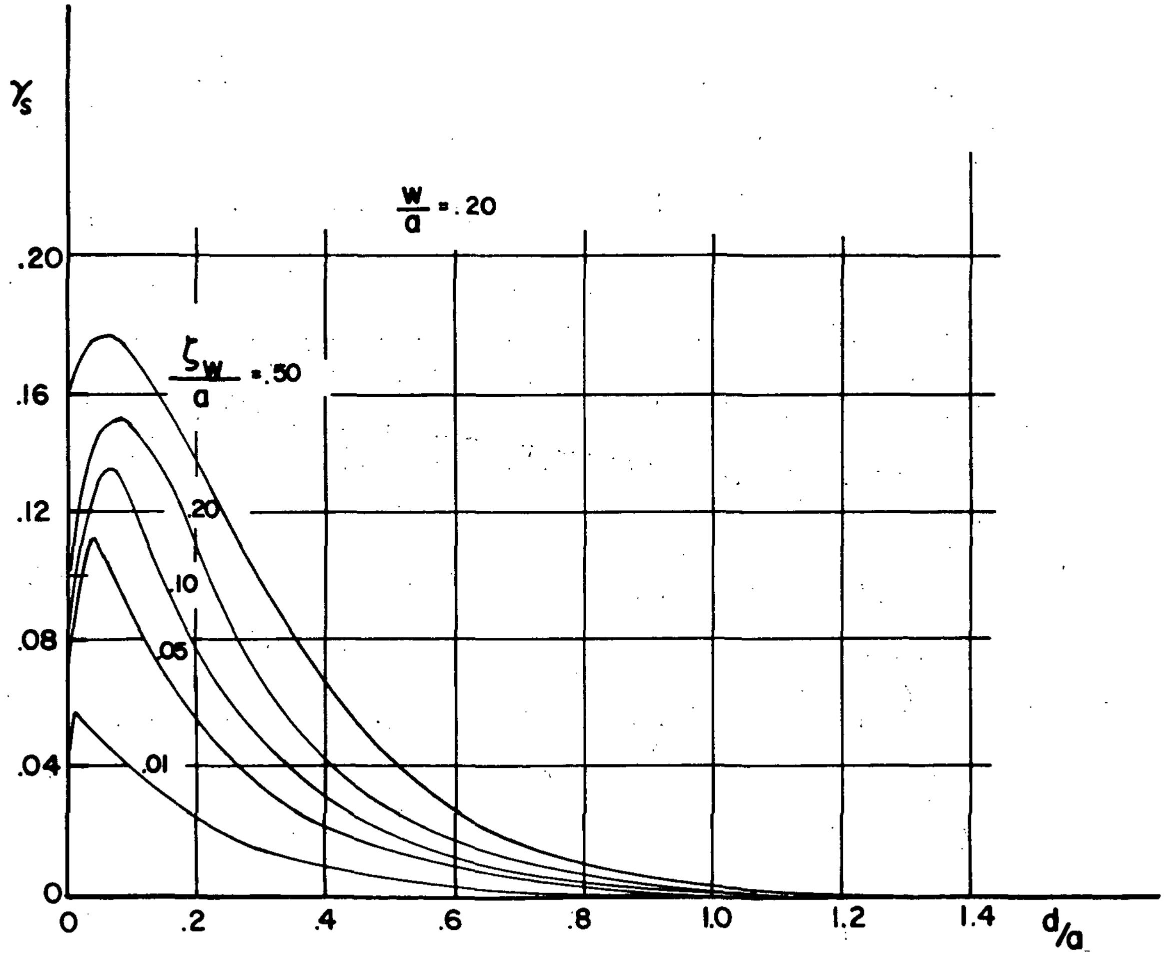


FIG. 11 a

DAMPING FACTOR VERSUS SURFACE AMPLITUDE FOR BAFFLE WIDTH W=.05a WITH BAFFLE LOCATION AS A PARAMETER (MILES FORMULA)

REVISED

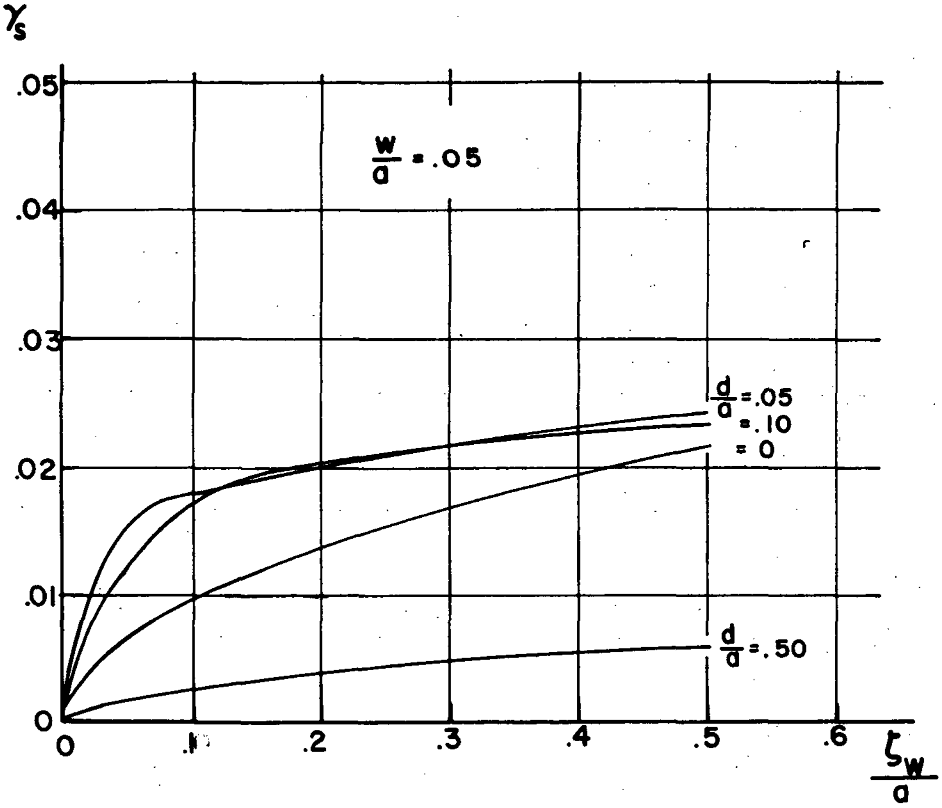
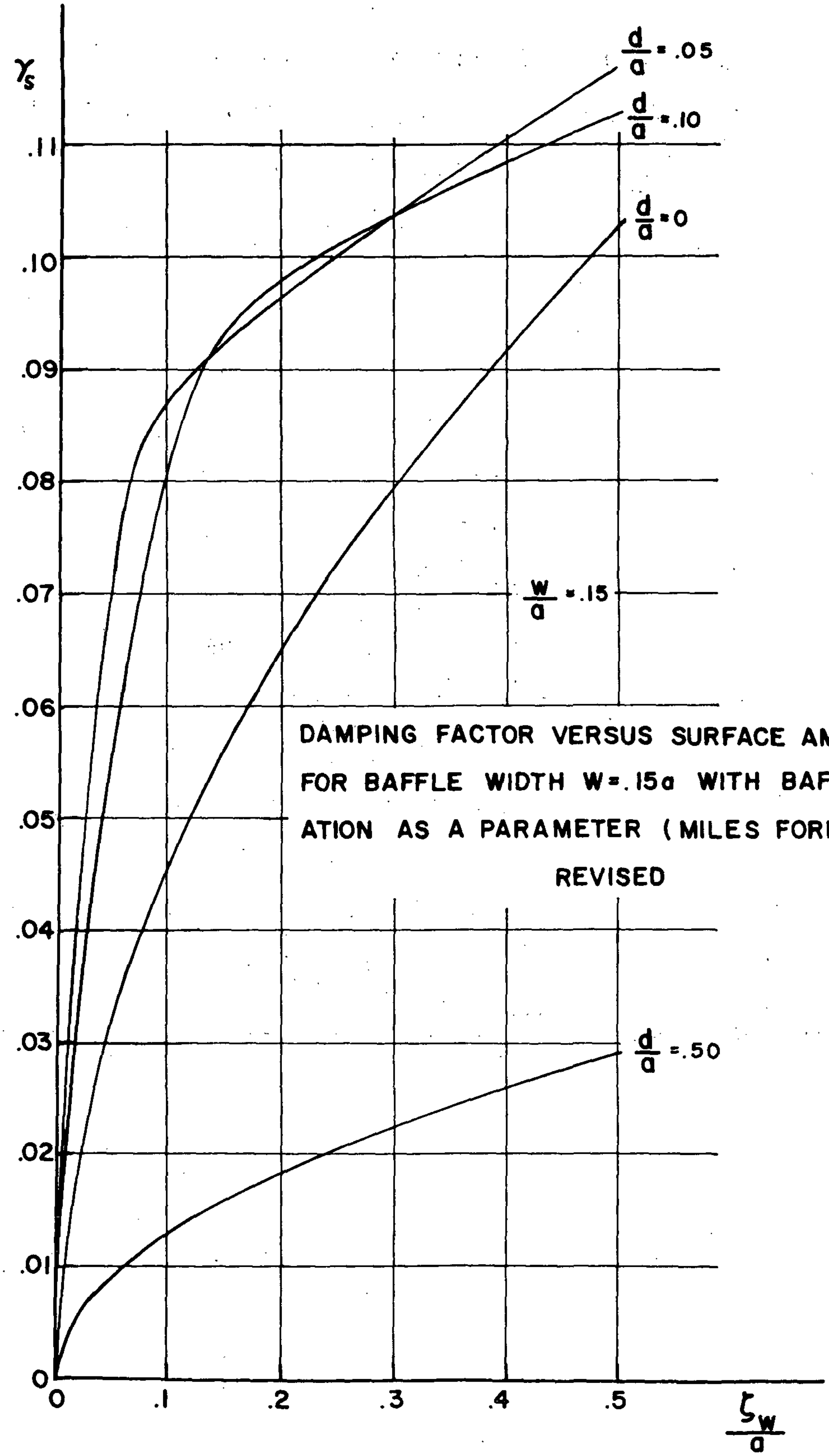


FIG. 11 b



DAMPING FACTOR VERSUS SURFACE AMPLITUDE FOR BAFFLE WIDTH W=.15a WITH BAFFLE LOCATION AS A PARAMETER (MILES FORMULA)

REVISED

FIG. 12 a

DAMPING FACTOR VERSUS BAFFLE WIDTH FOR

$\zeta_w = .10a$ WITH LOCATION OF BAFFLE AS A PARAMETER

(MILES FORMULA)

REVISED

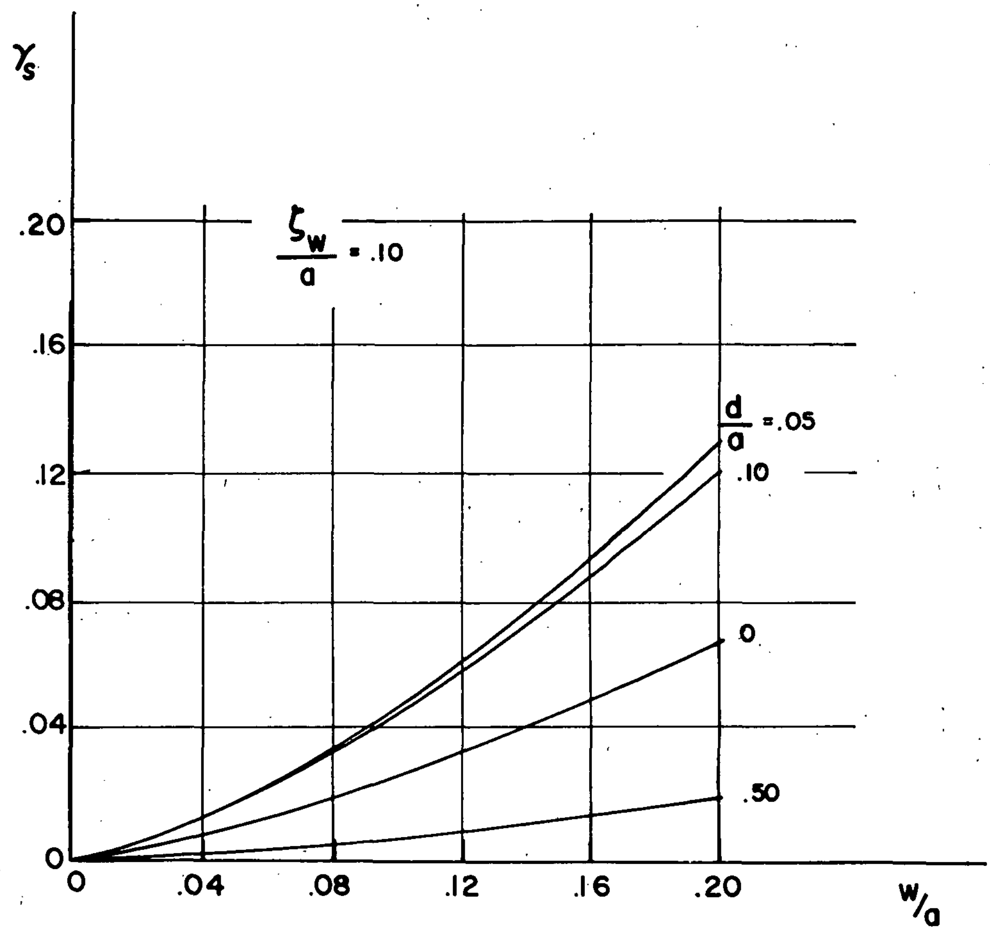


FIG. 12 b

DAMPING FACTOR VERSUS BAFFLE WIDTH FOR

$\zeta_W = .30a$ WITH LOCATION OF BAFFLE AS A PARAMETER

(MILES FORMULA)

REVISED

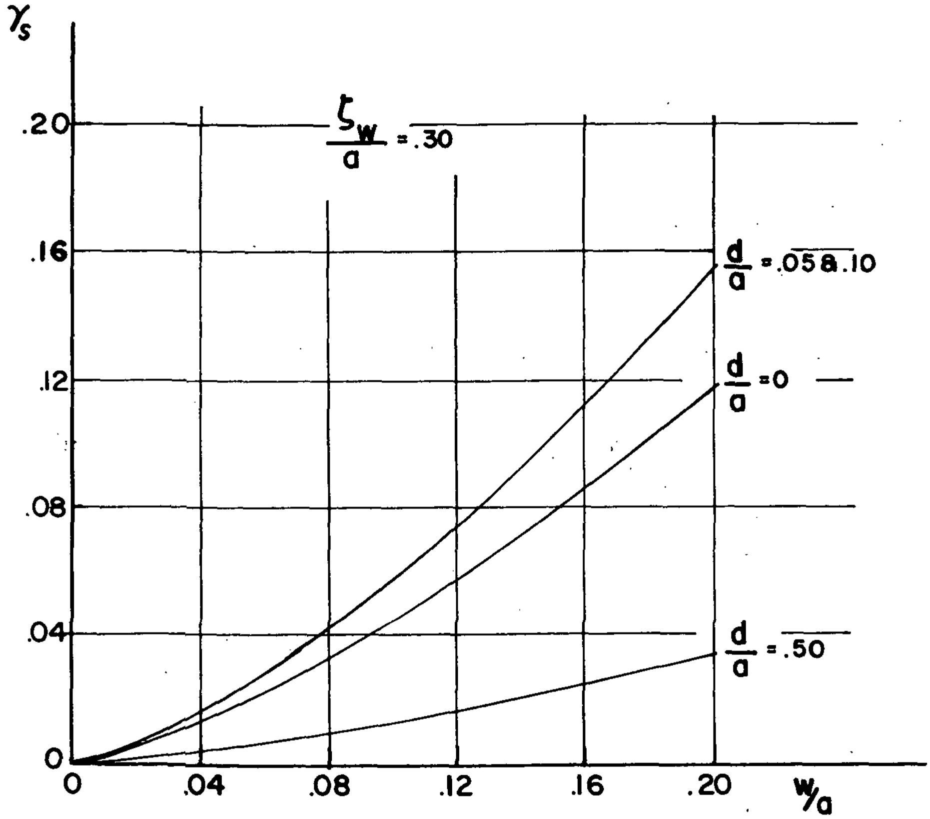


FIG. 13 a

DAMPING FACTOR VERSUS BAFFLE DEPTH FOR VARIOUS BAFFLE WIDTHS AND A LIQUID AMPLITUDE OF ζ_w=0.01a AND A BAFFLE DISTANCE FROM EACH OTHER D=0.2a

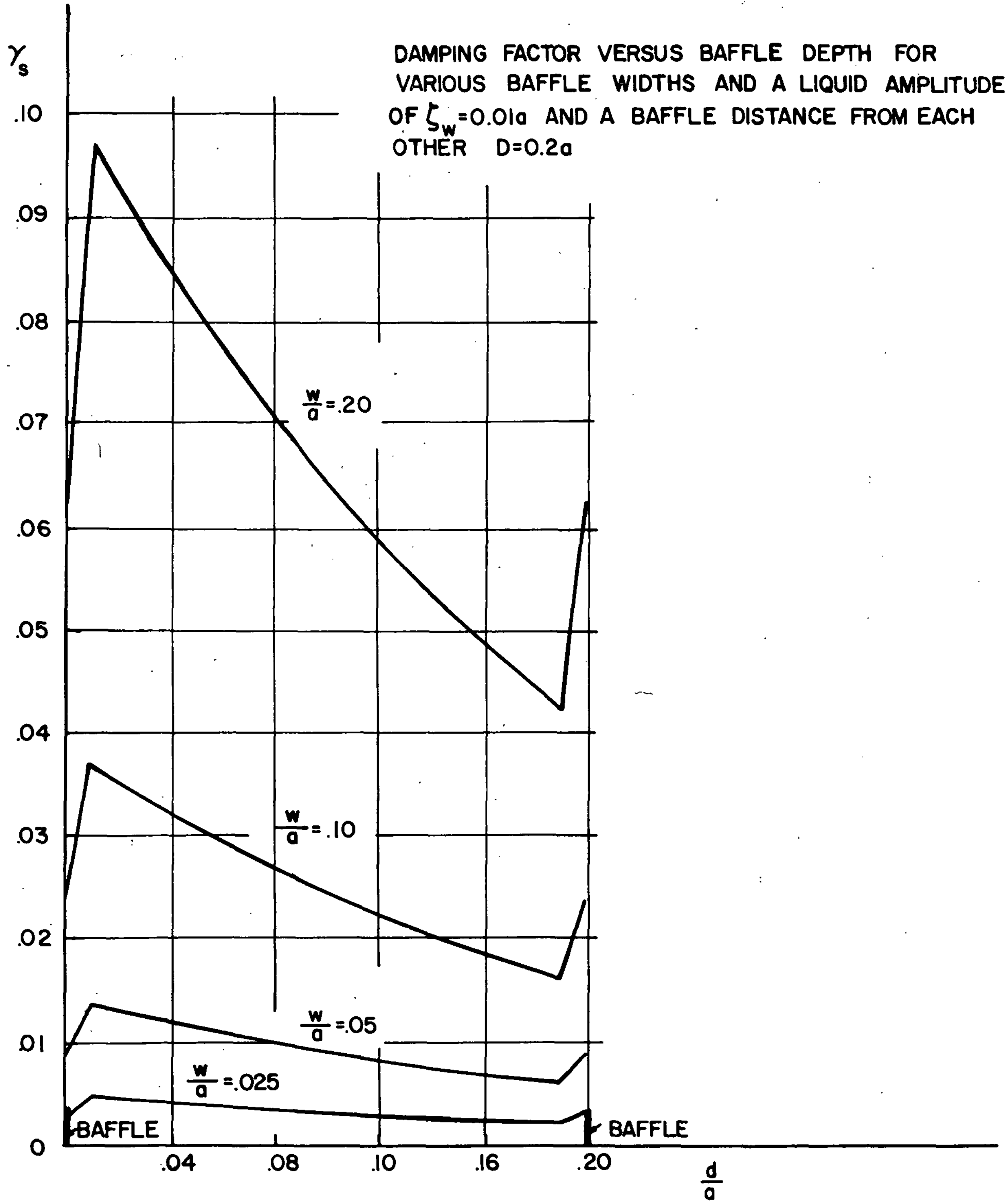
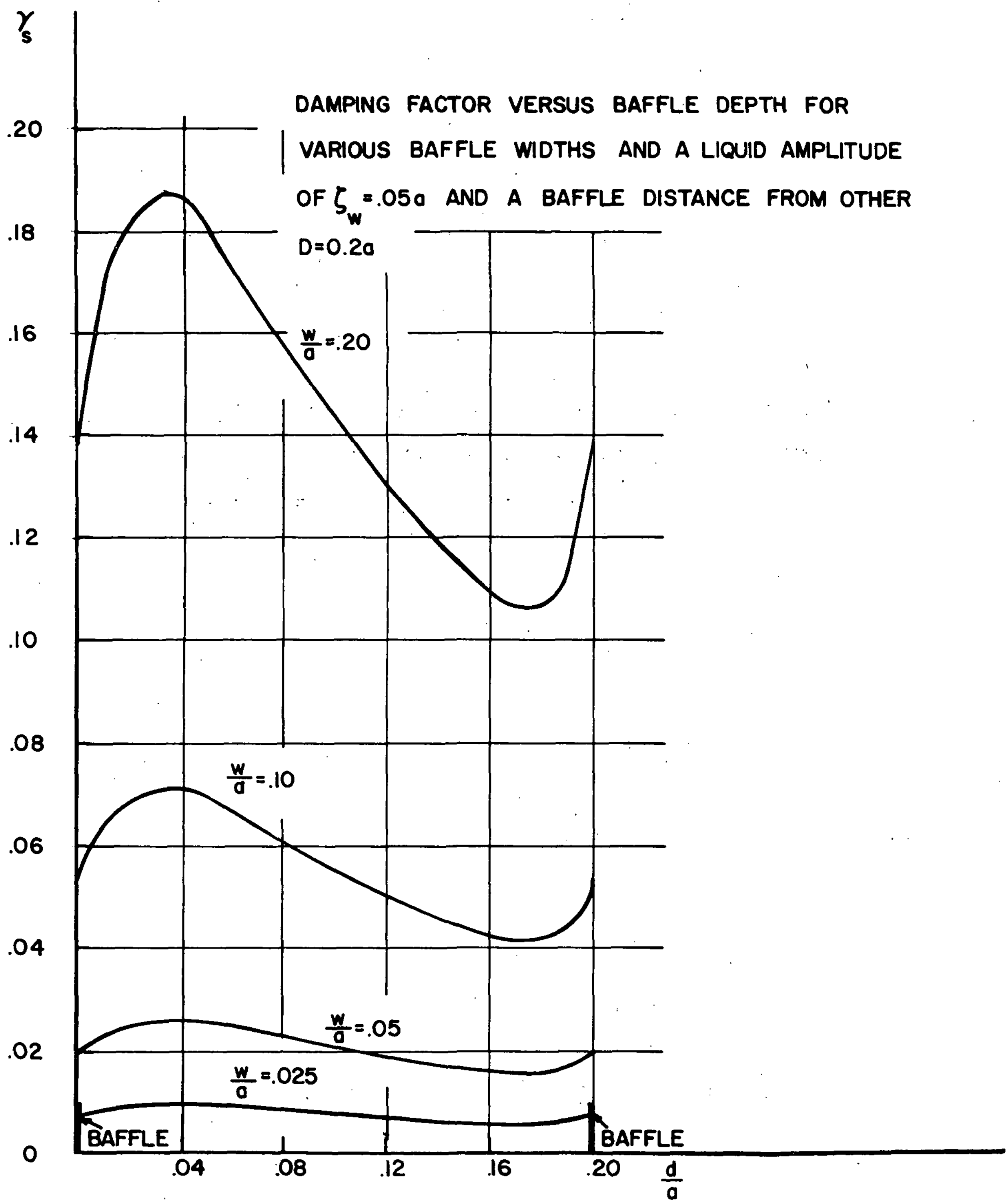
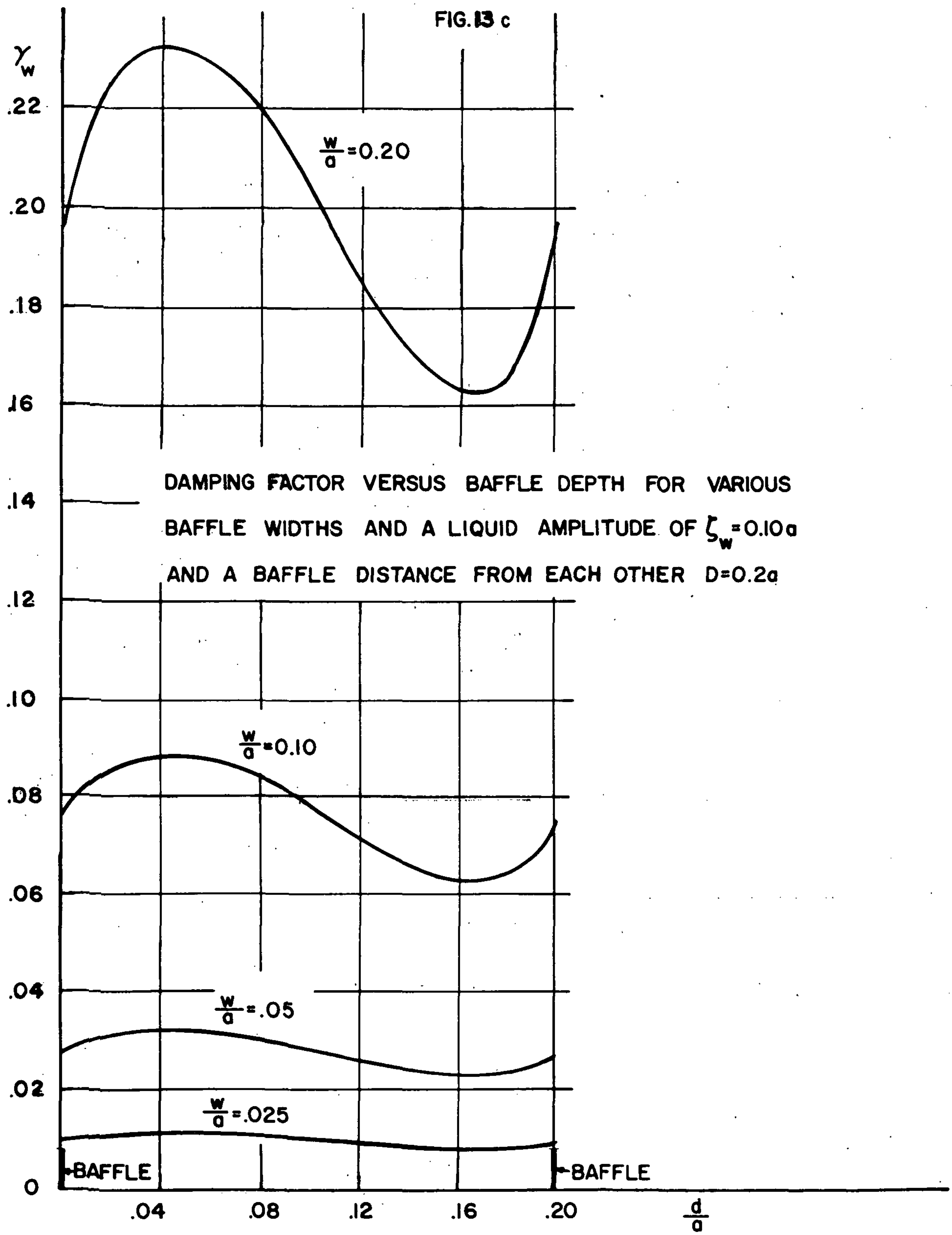


FIG. 13b



γ_s
DAMPING FACTOR VERSUS BAFFLE DEPTH FOR VARIOUS BAFFLE WIDTHS AND A LIQUID AMPLITUDE OF ζ_w = .05a AND A BAFFLE DISTANCE FROM OTHER D=0.2a
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
0
$\frac{w}{a}$ = .20
$\frac{w}{a}$ = .10
$\frac{w}{a}$ = .05
$\frac{w}{a}$ = .025
BAFFLE
BAFFLE
.04
.08
.12
.16
.20
$\frac{d}{a}$

FIG. 13 c



DAMPING FACTOR VERSUS BAFFLE DEPTH FOR VARIOUS BAFFLE WIDTHS AND A LIQUID AMPLITUDE OF $\zeta_w = 0.10a$ AND A BAFFLE DISTANCE FROM EACH OTHER $D = 0.2a$

FIG. 13 d

DAMPING FACTOR VERSUS BAFFLE DEPTH FOR VARIOUS BAFFLE WIDTHS AND A LIQUID AMPLITUDE OF $\zeta_w = 0.2a$ AND A BAFFLE DISTANCE FROM EACH OTHER $D = 0.2a$

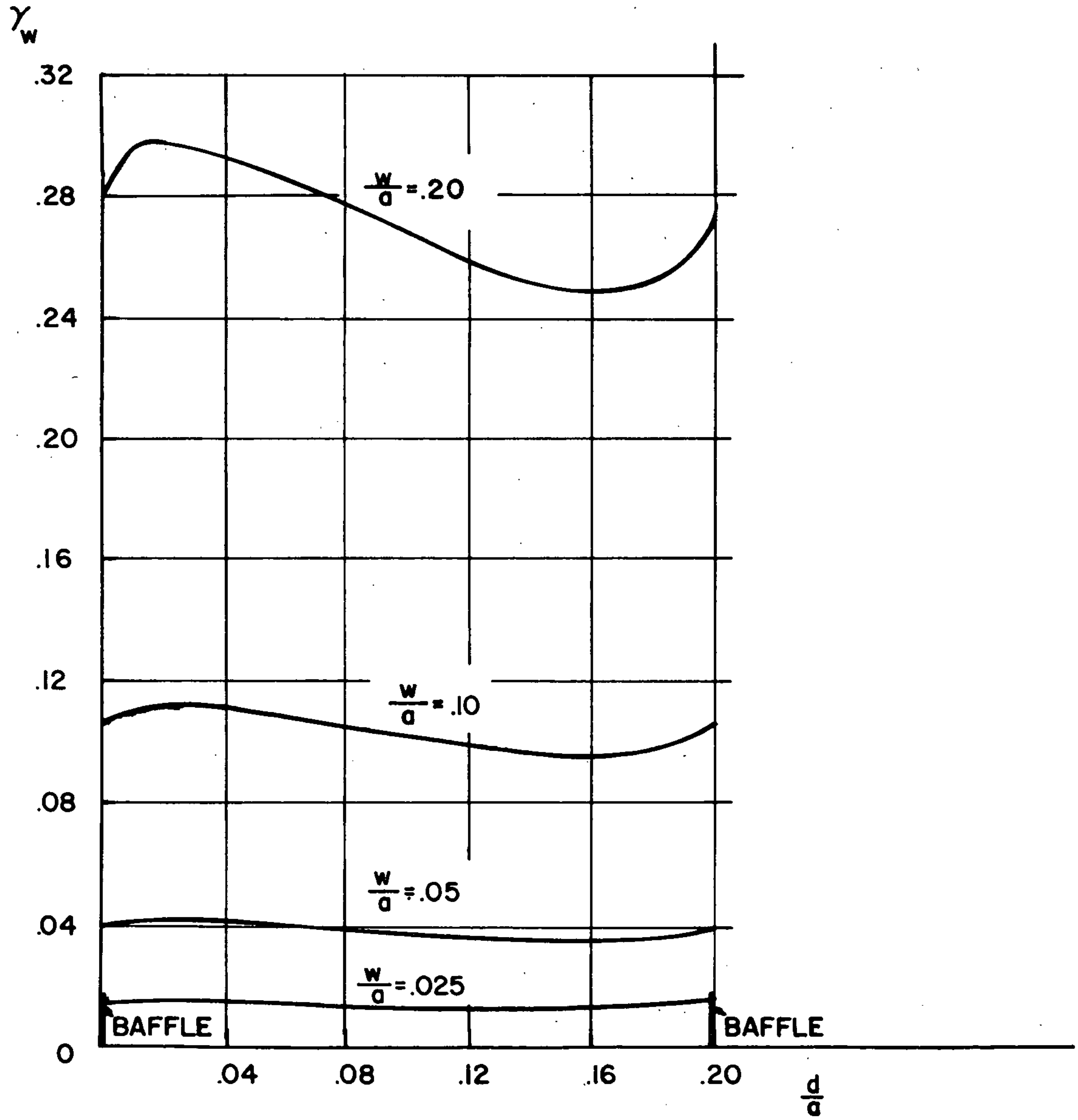


FIG. 13 e

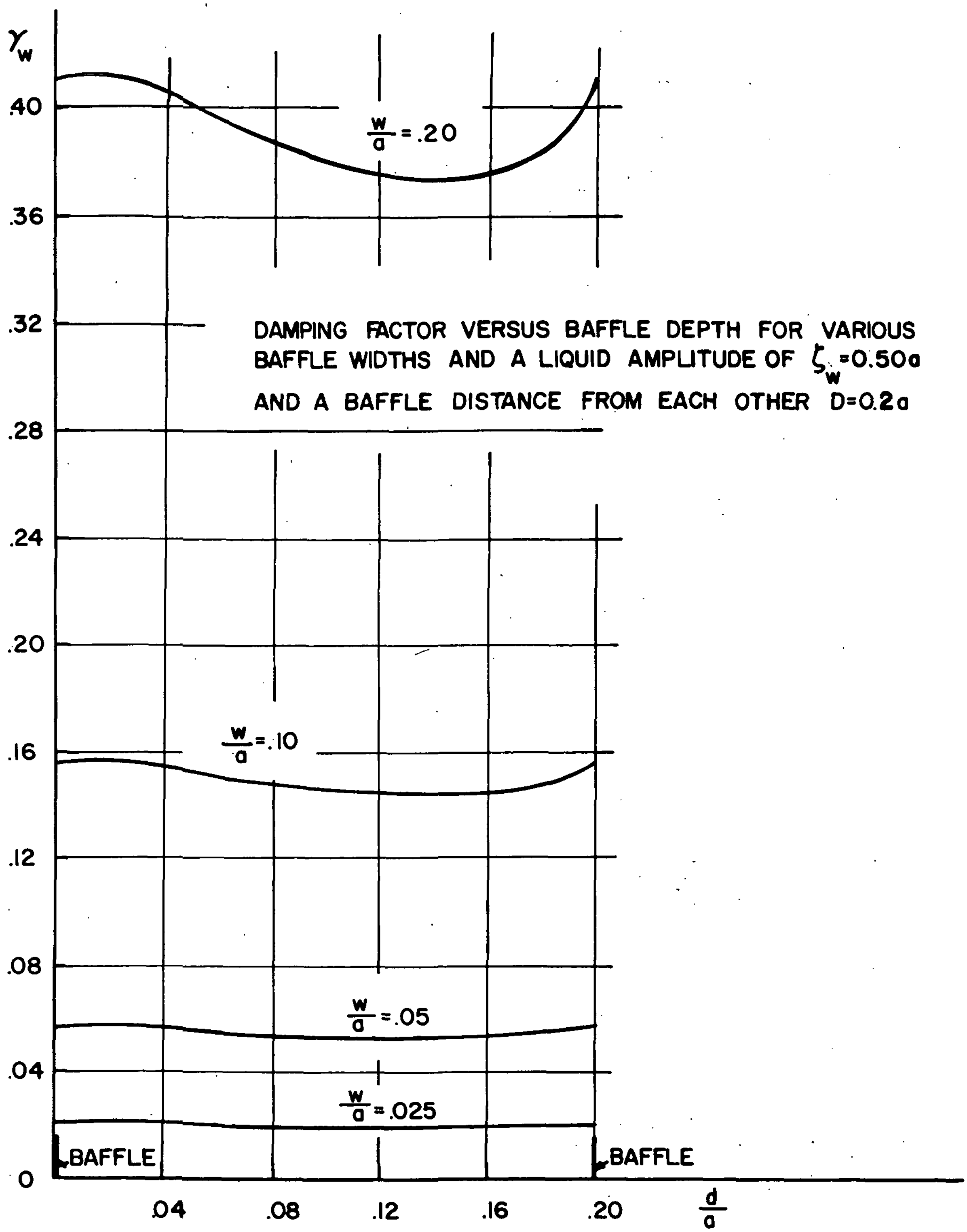
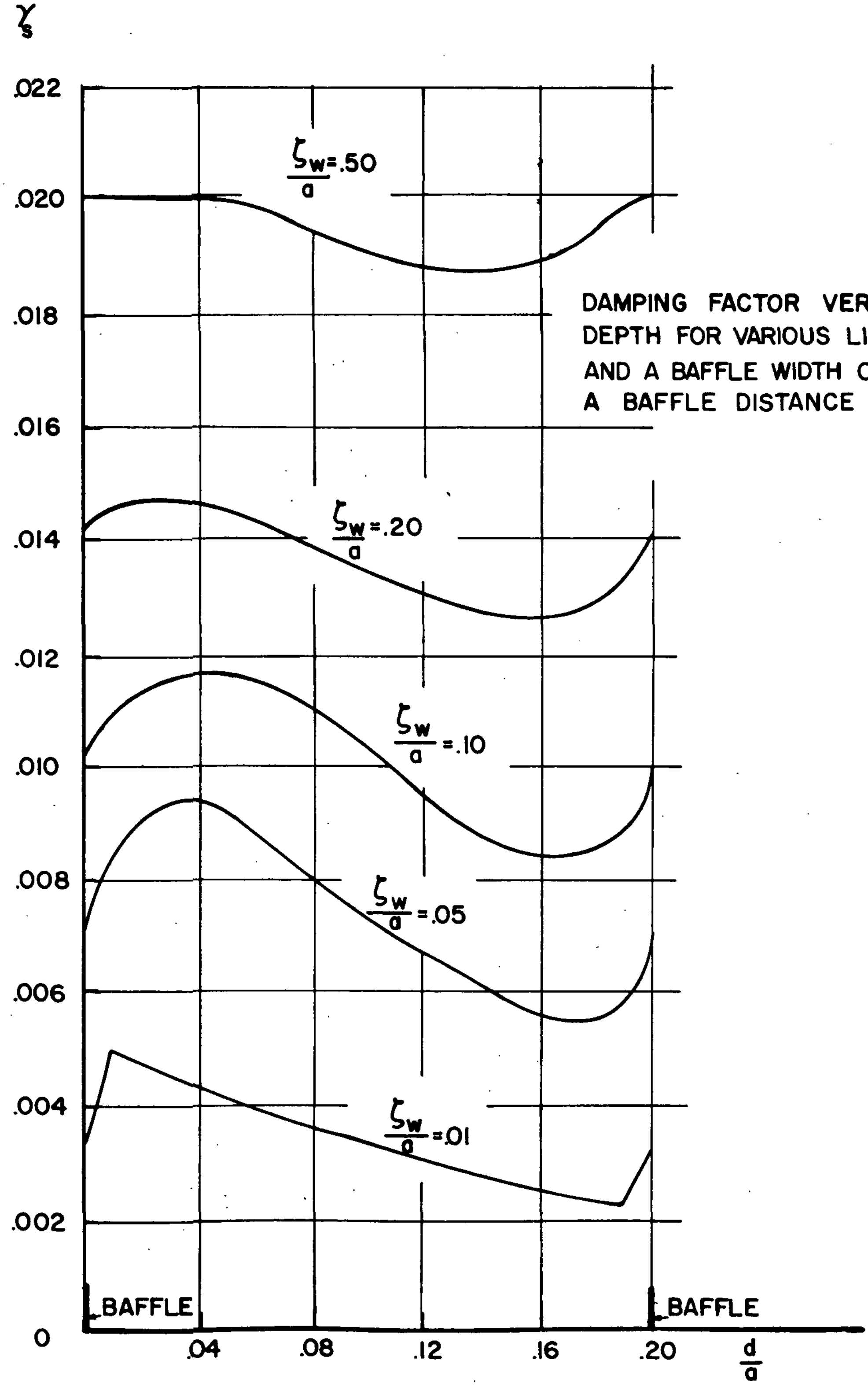

γw
.40
.36
.32
.28
.24
.20
.16
.12
.08
.04
0
w/a = .20
DAMPING FACTOR VERSUS BAFFLE DEPTH FOR VARIOUS BAFFLE WIDTHS AND A LIQUID AMPLITUDE OF ζw = 0.50a AND A BAFFLE DISTANCE FROM EACH OTHER D=0.2a
w/a = .10
w/a = .05
w/a = .025
BAFFLE
BAFFLE
.04
.08
.12
.16
.20
d/a

FIG. 14a



DAMPING FACTOR VERSUS BAFFLE DEPTH FOR VARIOUS LIQUID AMPLITUDE AND A BAFFLE WIDTH OF w=.025a AND A BAFFLE DISTANCE D=0.2a

FIG. 14b

DAMPING FACTOR VERSUS BAFFLE DEPTH FOR VARIOUS LIQUID AMPLITUDE AND A BAFFLE WIDTH OF w=.05a AND A BAFFLE DISTANCE D=0.2a

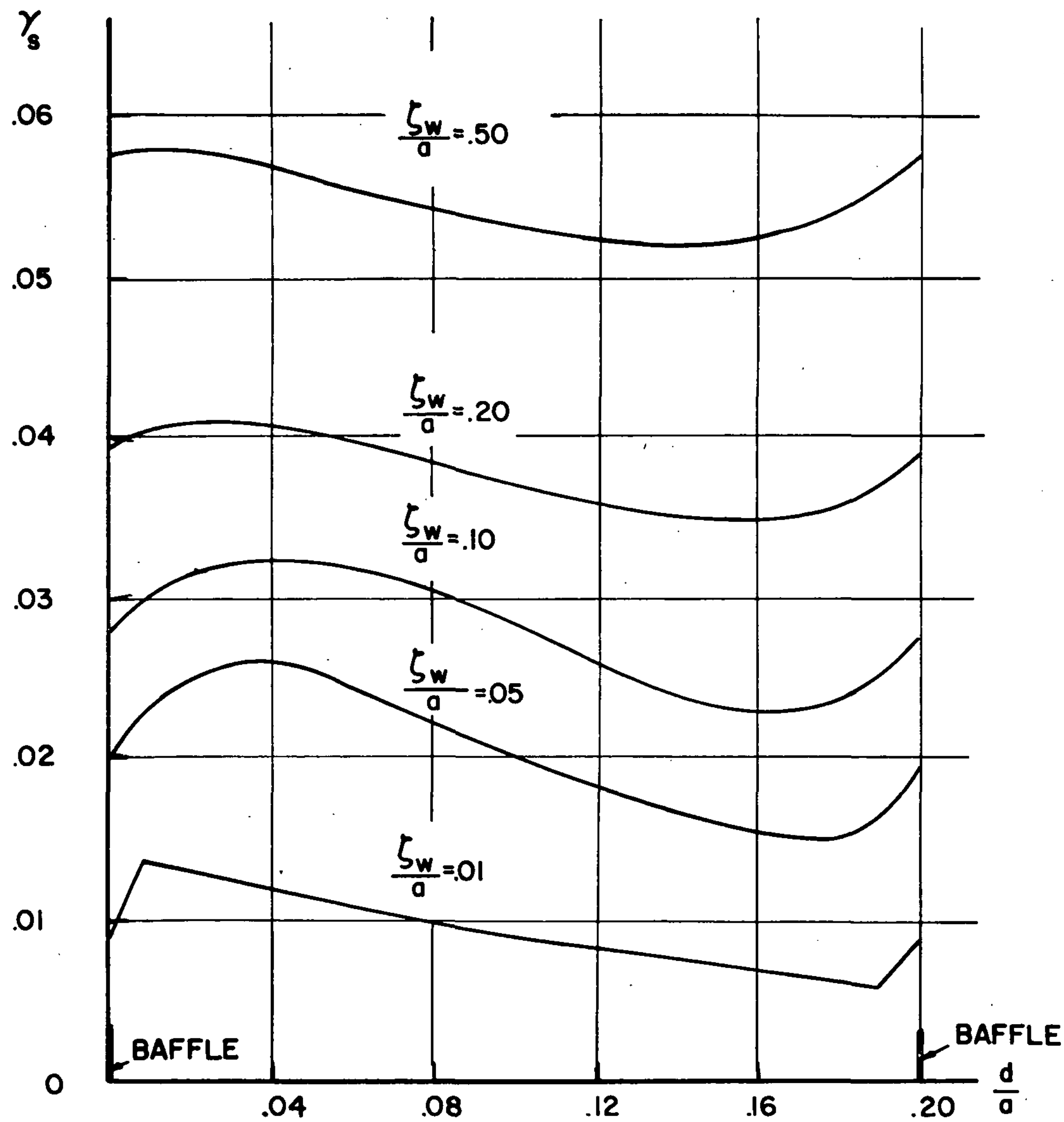
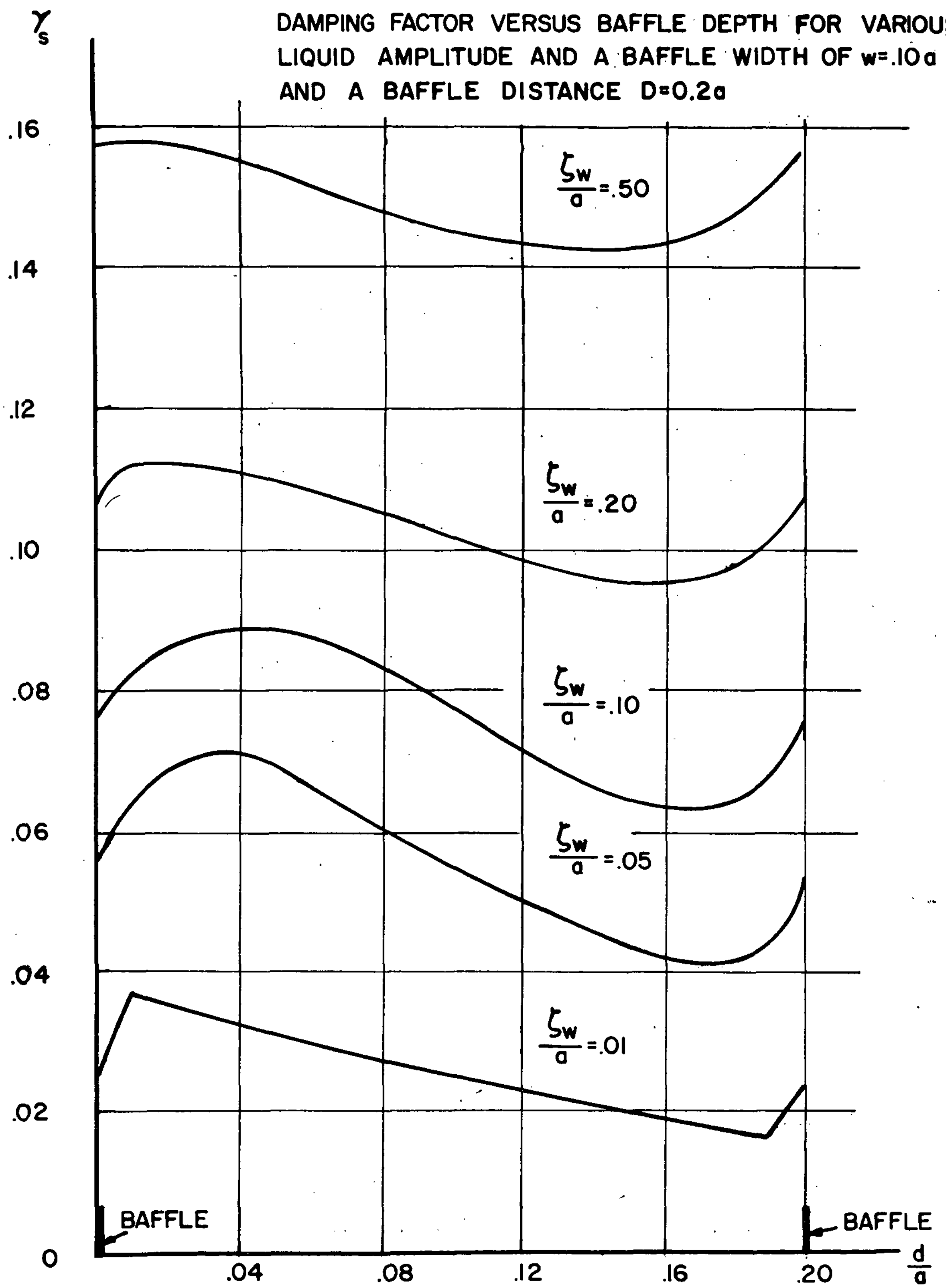
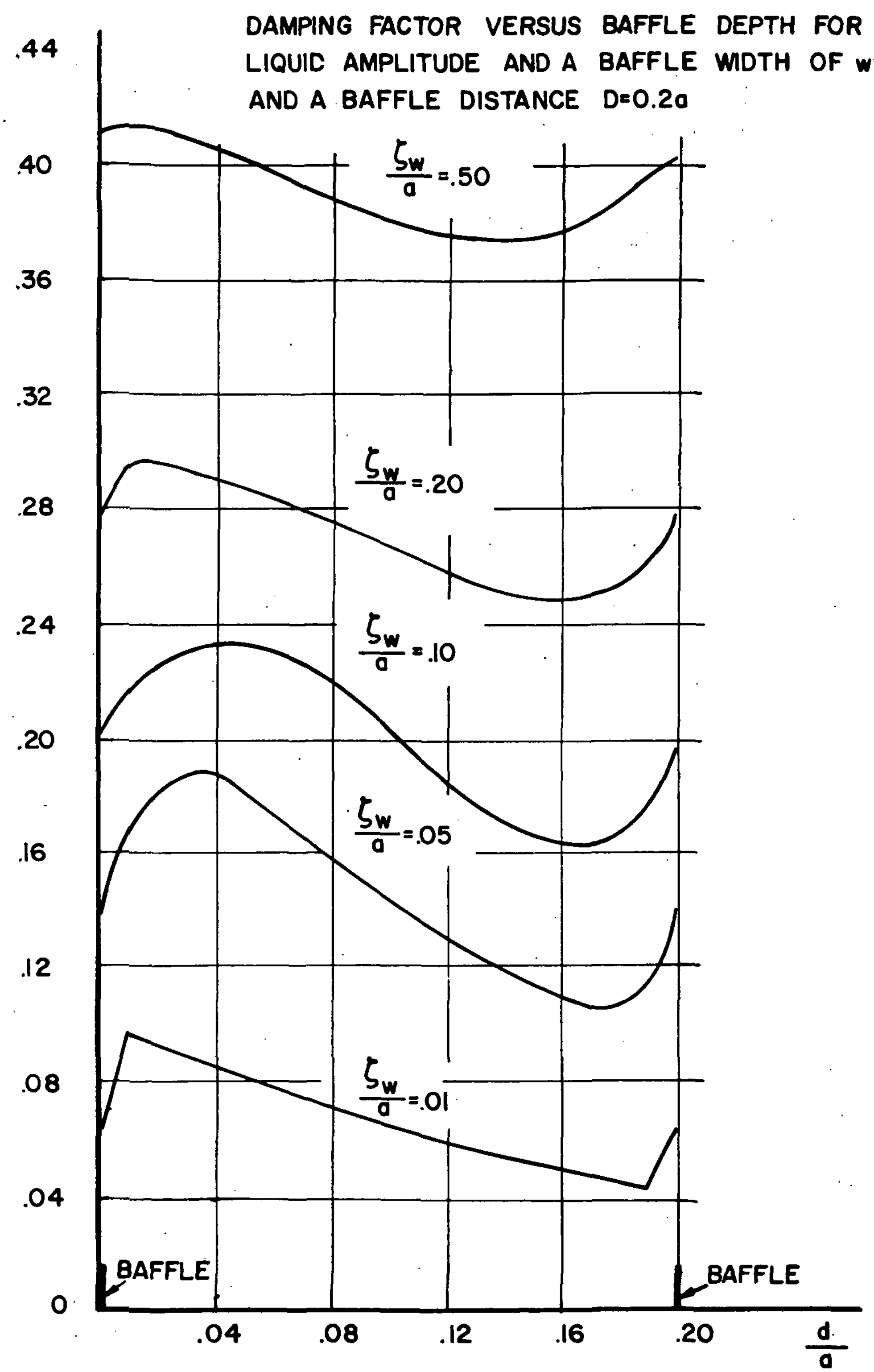


FIG. 14c



DAMPING FACTOR VERSUS BAFFLE DEPTH FOR VARIOUS LIQUID AMPLITUDE AND A BAFFLE WIDTH OF w=.10a AND A BAFFLE DISTANCE D=0.2a
γ_s
.16
.14
.12
.10
.08
.06
.04
.02
0
.04
.08
.12
.16
.20
$\frac{d}{a}$
$\frac{\zeta_w}{a}$=.50
$\frac{\zeta_w}{a}$=.20
$\frac{\zeta_w}{a}$=.10
$\frac{\zeta_w}{a}$=.05
$\frac{\zeta_w}{a}$=.01
BAFFLE
BAFFLE

FIG. 14d


DAMPING FACTOR VERSUS BAFFLE DEPTH FOR VARIOUS LIQUID AMPLITUDE AND A BAFFLE WIDTH OF w=0.2a AND A BAFFLE DISTANCE D=0.2a
.44
.40
.36
.32
.28
.24
.20
.16
.12
.08
.04
0
$\frac{\zeta_w}{a}$=.50
$\frac{\zeta_w}{a}$=.20
$\frac{\zeta_w}{a}$=.10
$\frac{\zeta_w}{a}$=.05
$\frac{\zeta_w}{a}$=.01
BAFFLE
BAFFLE
.04
.08
.12
.16
.20
$\frac{d}{a}$

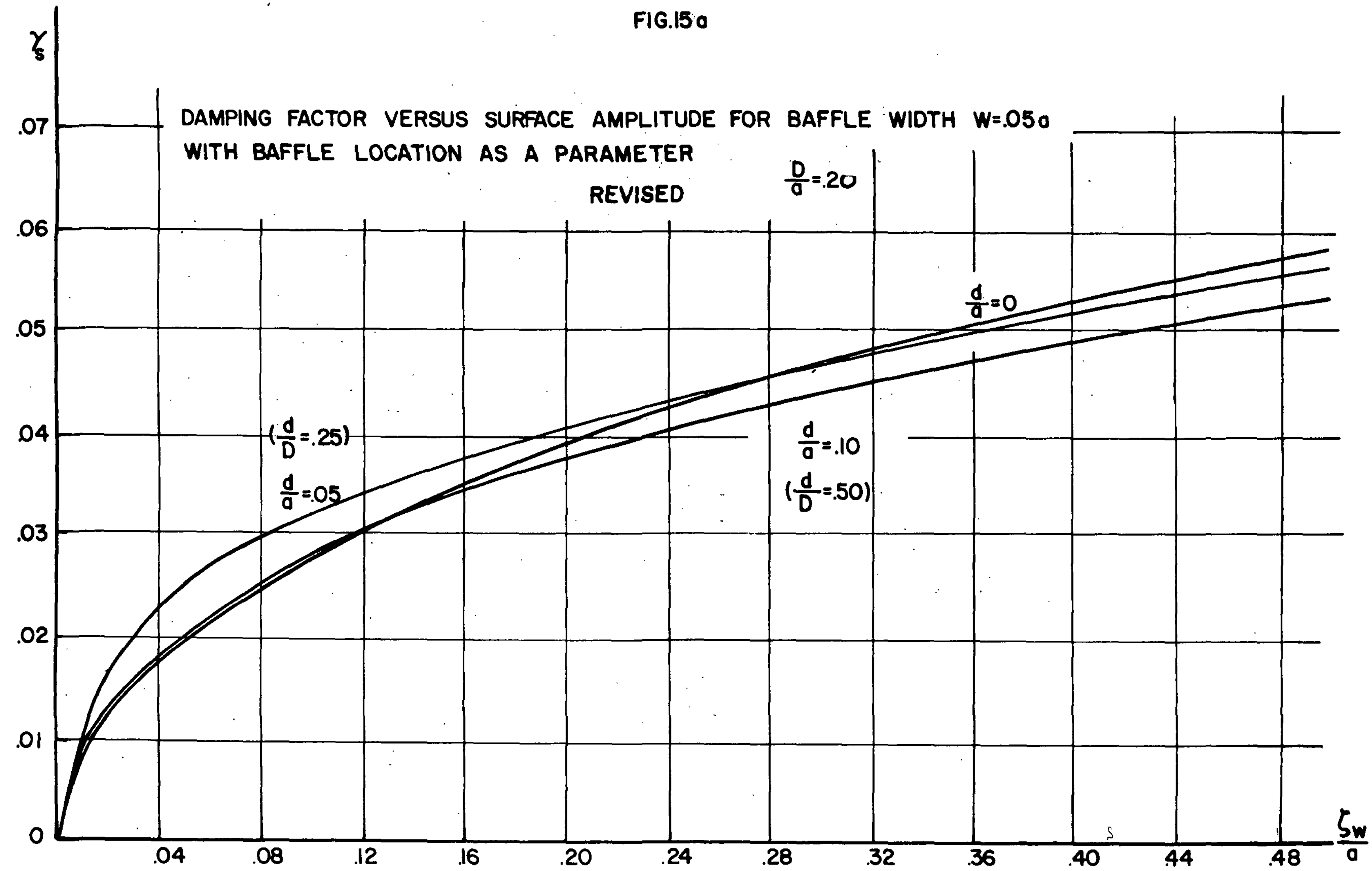


FIG. 15a

DAMPING FACTOR VERSUS SURFACE AMPLITUDE FOR BAFFLE WIDTH W=.05a
WITH BAFFLE LOCATION AS A PARAMETER
REVISED

FIG. 15 b

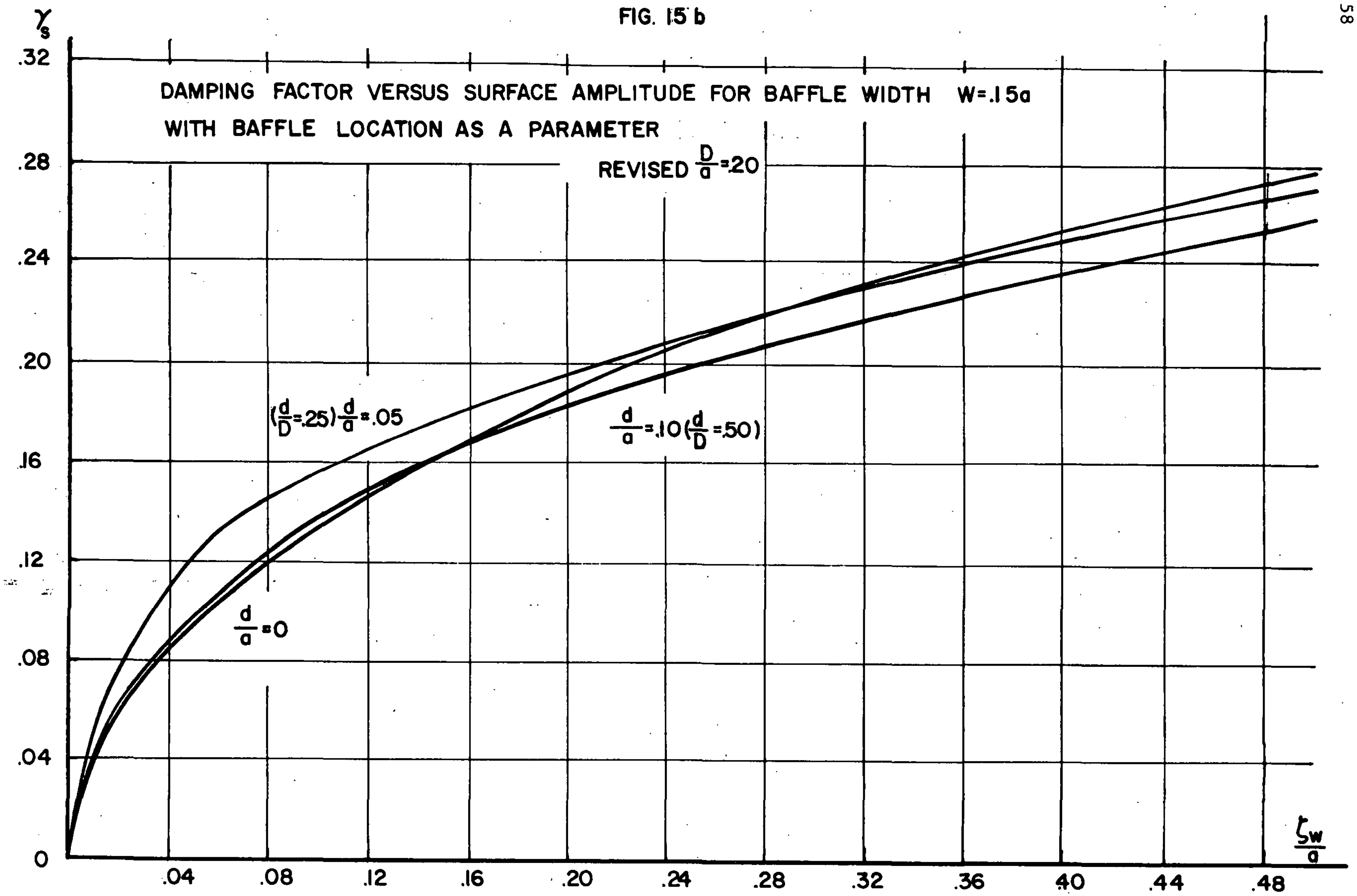

DAMPING FACTOR VERSUS SURFACE AMPLITUDE FOR BAFFLE WIDTH W=.15a
WITH BAFFLE LOCATION AS A PARAMETER
REVISED $\frac{D}{a}$=.20
$(\frac{d}{D}=.25)\ \frac{d}{a}=.05$
$\frac{d}{a}=.10\ (\frac{d}{D}=.50)$
$\frac{d}{a}=0$
γ_s
.32
.28
.24
.20
.16
.12
.08
.04
0
.04
.08
.12
.16
.20
.24
.28
.32
.36
.40
.44
.48
$\frac{\zeta_w}{a}$

FIG. 16 a

DAMPING FACTOR VERSUS BAFFLE WIDTH FOR $\zeta_w = .10a$ WITH LOCATION OF BAFFLE AS A PARAMETER

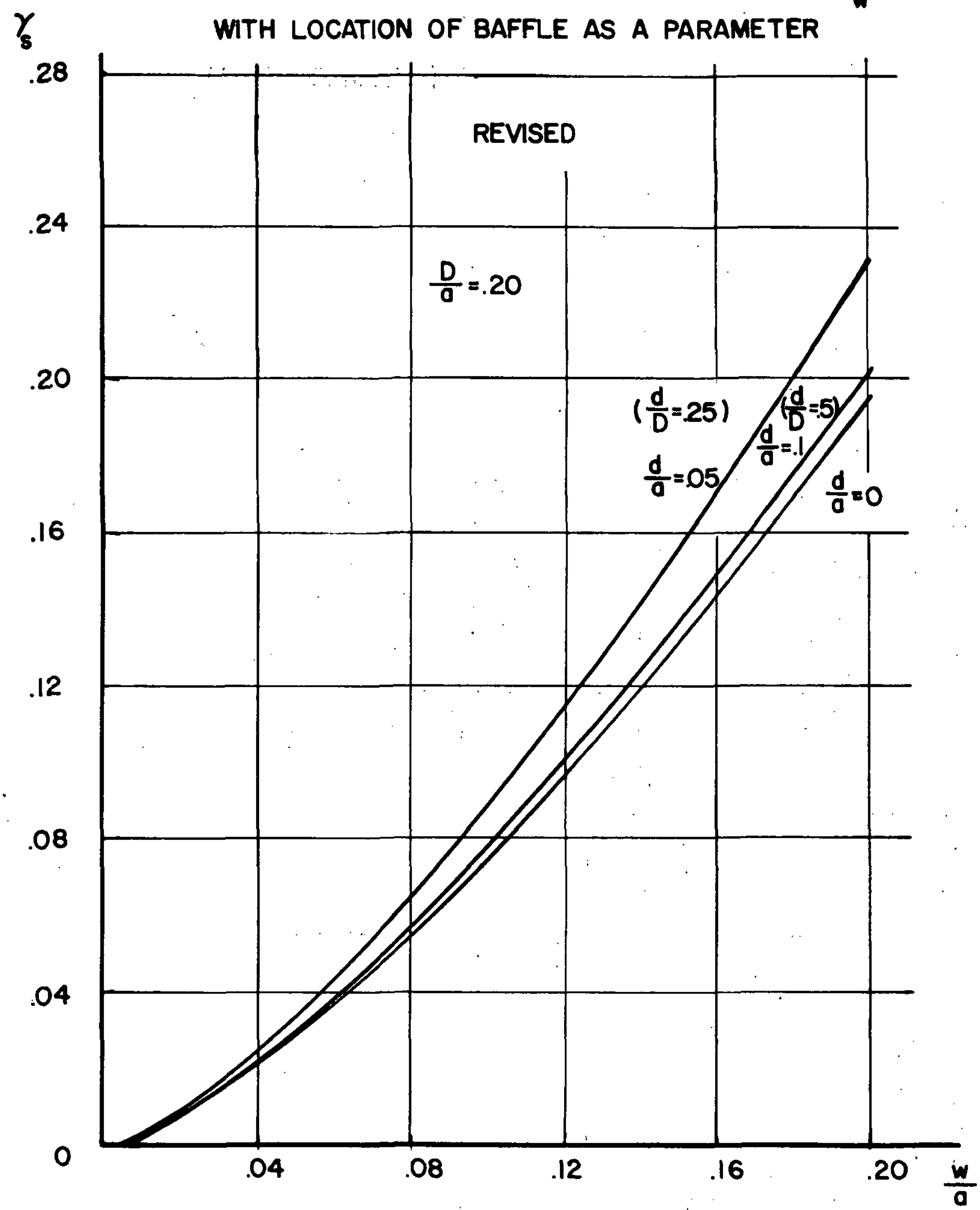


FIG. 16 b

DAMPING FACTOR VERSUS BAFFLE WIDTH FOR $\zeta_w = .3a$ WITH LOCATION OF BAFFLE AS A PARAMETER

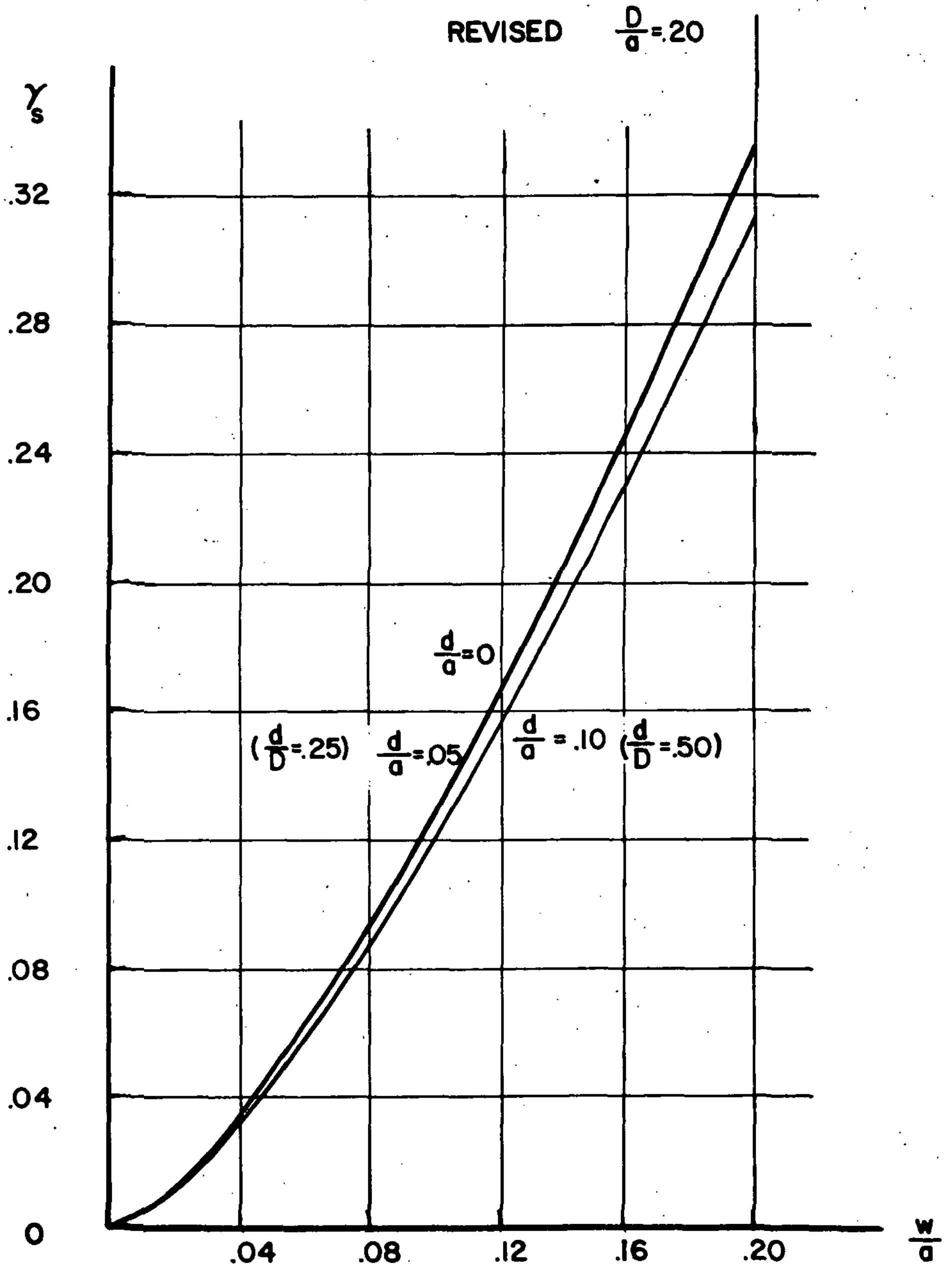
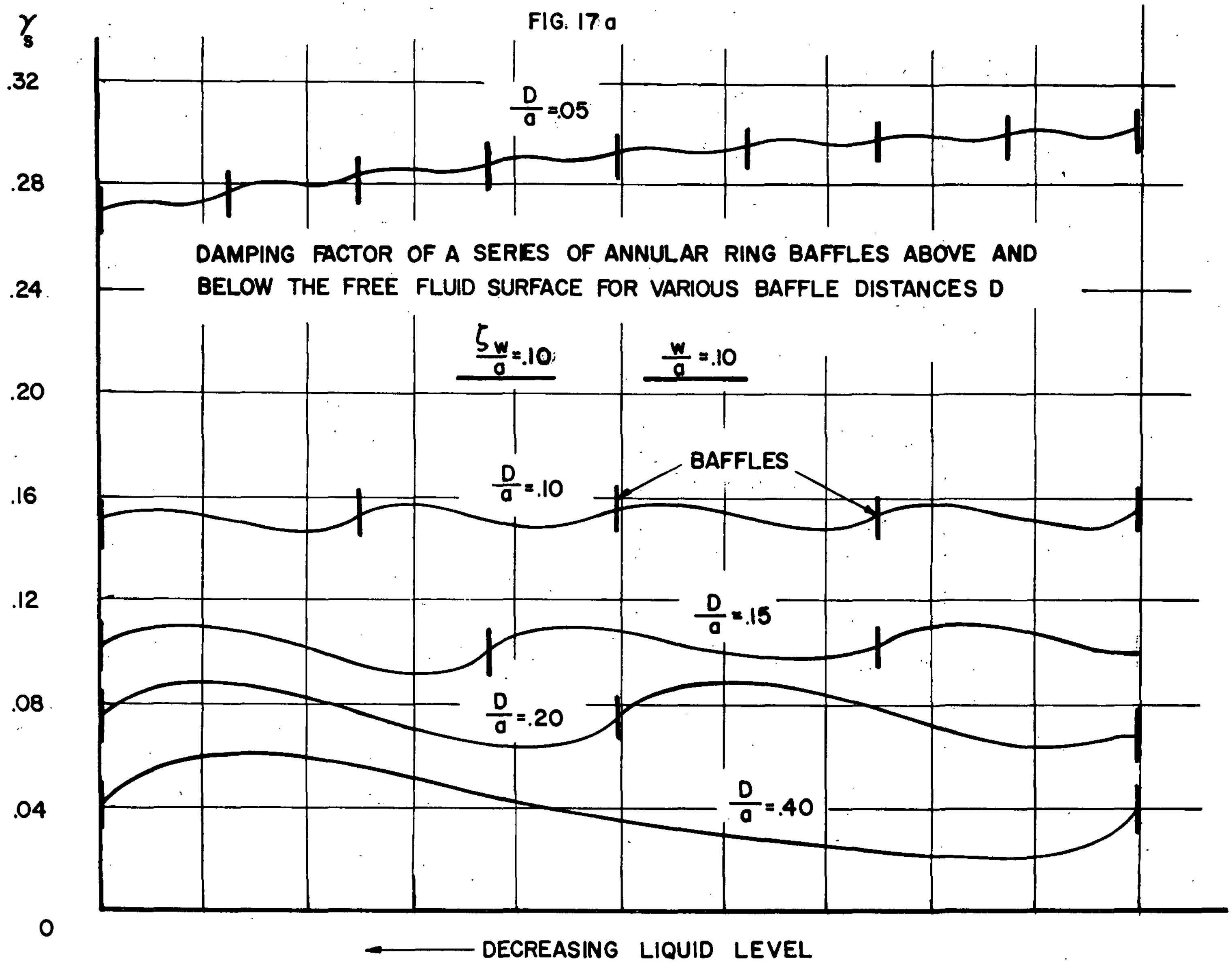
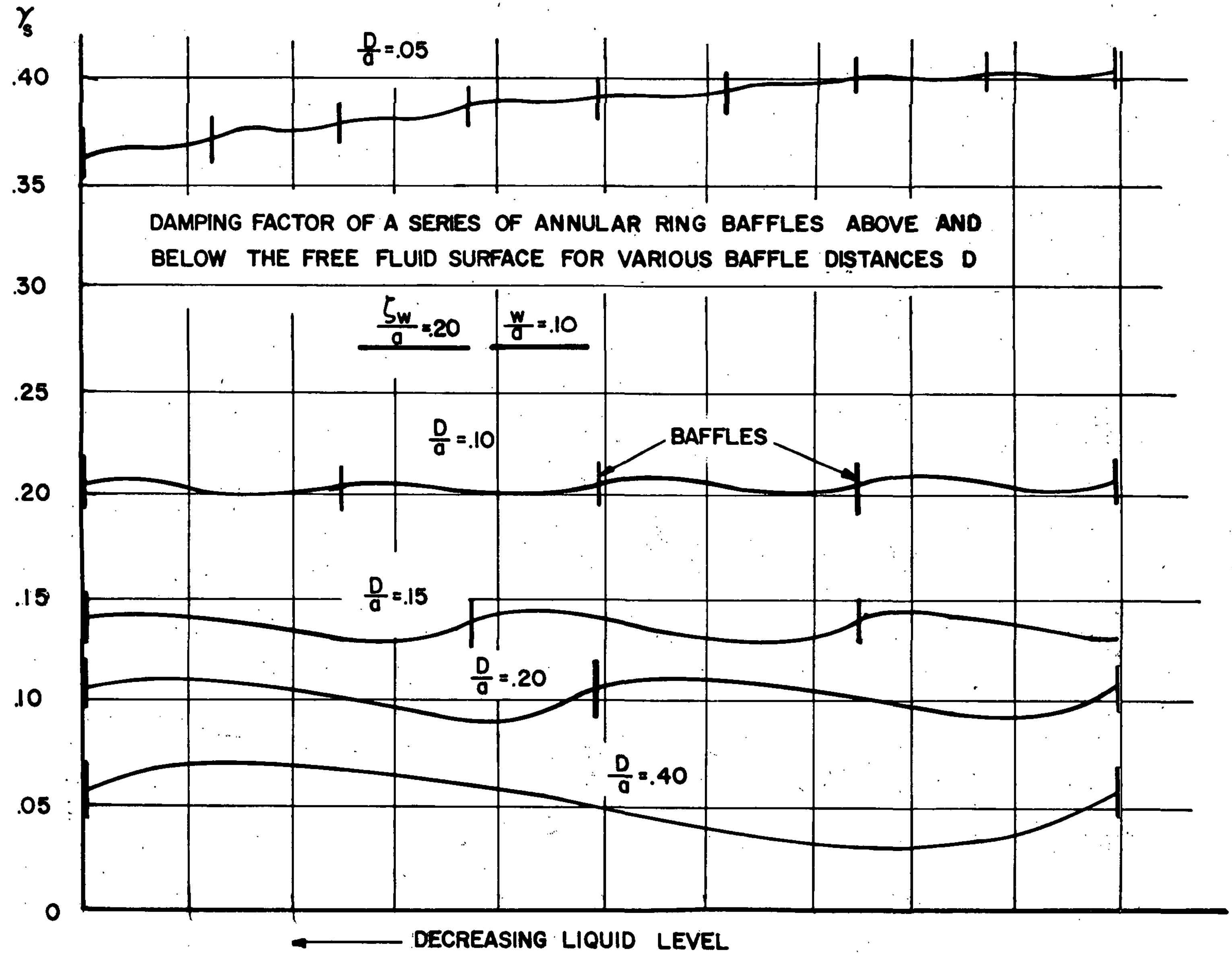


FIG. 17 a



DAMPING FACTOR OF A SERIES OF ANNULAR RING BAFFLES ABOVE AND BELOW THE FREE FLUID SURFACE FOR VARIOUS BAFFLE DISTANCES D

FIG. 17b



γ_s
.40
.35
.30
.25
.20
.15
.10
.05
0
$\frac{D}{a}=.05$
DAMPING FACTOR OF A SERIES OF ANNULAR RING BAFFLES ABOVE AND BELOW THE FREE FLUID SURFACE FOR VARIOUS BAFFLE DISTANCES D
$\frac{\zeta_w}{a}=.20$
$\frac{w}{a}=.10$
$\frac{D}{a}=.10$
BAFFLES
$\frac{D}{a}=.15$
$\frac{D}{a}=.20$
$\frac{D}{a}=.40$
DECREASING LIQUID LEVEL

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APPROVAL MTP-AERO-62-81

THE DAMPING FACTOR PROVIDED BY FLAT ANNULAR RING BAFFLES FOR FREE FLUID SURFACE OSCILLATIONS

HELMUT F. BAUER

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